AEFA Project No. 89-14

PRELIMINARY AIRWORTHINESS EVALUATION OF THE WOODWARD HYDROMECHANICAL UNIT INSTALLED ON T700-GE-700 ENGINES IN THE UH-60A HELICOPTER

Joseph L. Piotrowski
Project Officer

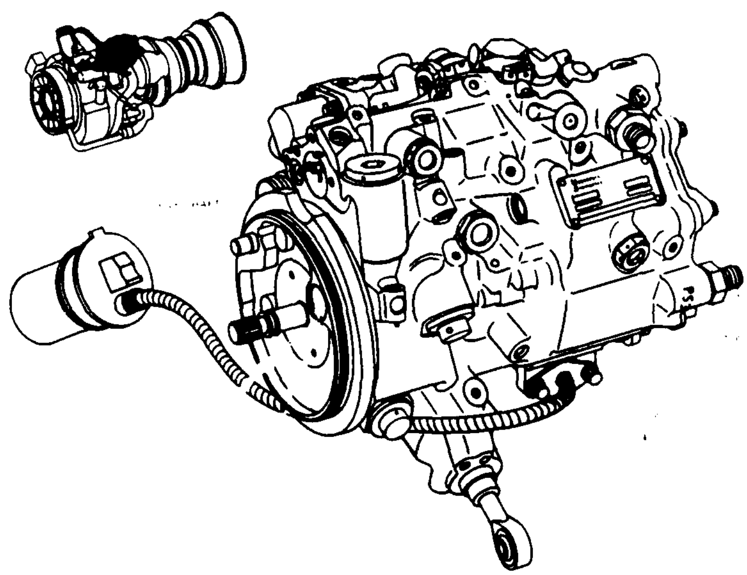
Christopher J. Young
Project Engineer

Thomas P. Walsh
MAJ, AV
Project Pilot

Julie Sandman
CPT, AV
Project Pilot

August 1989

Final Report



Approved for public release, distribution unlimited.

AEFA

AVIATION ENGINEERING FLIGHT ACTIVITY
Edwards Air Force Base, California 93523-5000

DISCLAIMER NOTICE

The findings of this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

DISPOSITION INSTRUCTIONS

Destroy this report when it is no longer needed. Do not return it to the originator.

TRADE NAMES

The use of trade names in this report does not constitute an official endorsement or approval of the use of the commercial hardware and software.

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	**1b. RESTRICTIVE MARKINGS**
2a. SECURITY CLASSIFICATION AUTHORITY U.S. ARMY AVIATION SYSTEMS COMMAND	**3. DISTRIBUTION/AVAILABILITY OF REPORT**
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) AEFA PROJECT NO. 89-14	**5. MONITORING ORGANIZATION REPORT NUMBER(S)**
6a. NAME OF PERFORMING ORGANIZATION U.S. ARMY AVIATION ENGINEERING FLIGHT ACTIVITY — **6b. OFFICE SYMBOL** *(If applicable)*	**7a. NAME OF MONITORING ORGANIZATION**
6c. ADDRESS *(City, State, and ZIP Code)* EDWARDS AIR FORCE BASE, CALIFORNIA 93523-5000	**7b. ADDRESS** *(City, State, and ZIP Code)*
8a. NAME OF FUNDING/SPONSORING ORGANIZATION U.S. ARMY AVIATION SYSTEMS COMMAND — **8b. OFFICE SYMBOL** *(If applicable)*	**9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER**
8c. ADDRESS *(City, State, and ZIP Code)* 4300 GOODFELLOW BLVD. ST. LOUIS, MO 63120-1798	**10. SOURCE OF FUNDING NUMBERS**

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
68-9BE456-01	68-EC		

11. TITLE *(Include Security Classification)*
Preliminary Airworthiness Evaluation of the Woodward Hydromechanical Unit Installed on T700-GE-7000 Engines In the UH-60A Helicopter

12. PERSONAL AUTHOR(S)
Joseph L. Piotrowski, Christopher J. Young, MAJ Thomas P. Walsh, CPT Julie Sandman

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT *(Year, Month, Day)*	15. PAGE COUNT
FINAL	FROM 14/05/89 TO 14/06/89	August 1989	62

16. SUPPLEMENTARY NOTATION

17. COSATI CODES		
FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*
Engine/Rotor Transient Droop Characteristics, Preliminary Worthiness Evaluation, Woodward Hydromechanical Unit, T700-GE-700

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

The U.S. Army Aviation Engineering Flight Activity conducted a Preliminary Airworthiness Evaluation of the Woodward Hydromechanical Unit (HMU) installed on T700-GE-700 engines in the UH-60A helicopter from 14 May 1989 to 14 June 1989. The evaluation was conducted at Edwards AFB, California (elevation 2302 feet) and Coyote Flat, California (elevation 9980 feet) on aircraft S/N 88-26015. The evaluation consisted of eleven flights for a total of 15.5 productive flight hours. Performance of the Woodward HMU and the Hamilton Standard HMU, presently used on T700-GE-700 engines, was similar. The poor engine/rotor transient droop characteristics, as noted in previous testing, remain a shortcoming regardless of the HMU installed. Operation of T700-GE-700 engines with Woodward HMUs installed is satisfactory.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	**21. ABSTRACT SECURITY CLASSIFICATION** UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL SHEILA R. LEWIS	**22b. TELEPHONE** *(Include Area Code)* (805) 277-2115 — **22c. OFFICE SYMBOL** SAVTE-PR

DD Form 1473, JUN 86 — *Previous editions are obsolete.*

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

TABLE OF CONTENTS

	PAGE
INTRODUCTION	
Background	1
Test Objective	1
Description	1
Test Scope	2
Test Methodology	4
RESULTS AND DISCUSSION	
General	5
Installation Procedures	5
Mechanical Characteristics	6
Engine Start Characteristics	6
Engine Restarts in Flight	6
Engine Trim Response	8
Isochronous Governing Characteristics	8
Engine/Airframe Response	8
Engine/Drive Train Stability	9
Electrical Control Unit (ECU) Lockout	9
Engine Shutdown	9
Engine Flameout Conditions	9
CONCLUSIONS	
General	12
Shortcoming	12
RECOMMENDATIONS	13
APPENDIXES	
A. References	14
B. Description	15
C. Instrumentation	23
D. Test Techniques and Data Analysis Methods	26
E. Test Data	29
DISTRIBUTION	

INTRODUCTION

BACKGROUND

1. The General Electric Company (GEC), which produces T700-GE-700 engines, contracted with the Woodward Governor Company (WGC) as a second source for procurement of the Hydromechanical Unit (HMU) used on T700 engines. Sikorsky Aircraft performed limited flight testing of a UH-60A helicopter with a WGC HMU installed on one of its T700-GE-700 engines and experienced flameouts at low power settings at approximately 15,000 ft pressure altitude. Other problems encountered included throttle bracket interference, throttle rigging differences, and sub-idle fuel flow modulations. After reviewing Sikorsky Aircraft's flight test results and subsequent analysis, GEC and WGC determined that six modifications were needed to eliminate demonstrated and potential operational deficiencies of the WGC HMU. The U.S. Army Aviation Engineering Flight Activity (AEFA) was tasked by the U.S. Army Aviation Systems Command to evaluate the operational characteristics of the modified WGC HMU installed on T700-GE-700 engines (ref 1, app A).

TEST OBJECTIVE

2. The objective of this test was to evaluate the WGC HMU installed on T700-GE-700 engines in the UH-60A helicopter.

DESCRIPTION

3. The UH-60A Black Hawk helicopter is a twin turbine engine, single main rotor helicopter capable of transporting cargo, 11 combat troops and weapons during day and night visual, and instrument meteorological conditions. The helicopter is equipped with conventional wheel type landing gear and four bladed main and tail rotors. The helicopter is powered by two T700-GE-700 turboshaft engines each having an installed thermodynamic rating (30 minute) of 1584 shaft horsepower (shp) at sea level, standard atmosphere static conditions. Installed dual engine power is transmission limited to 2828 shp. Engine governing is provided by the integrated operation of a HMU and an Electrical Control Unit. Engine control features include: fuel flow scheduling, isochronous power turbine/main rotor (N_P/N_R) governing, automatic turbine gas temperature limiting, Np overspeed protection, and automatic load sharing.

4. Control of fuel to the engine is performed by the HMU. The HMU contains a high pressure pump that delivers fuel into the combustor. Various parameters are sensed by the HMU and influence fuel flow and variable stator vane position. The HMU responds to two separate mechanical linkage inputs from the cockpit. A collective pitch linkage provides load demand changes and the Engine Power Control Lever provides power changes to the HMU.

5. The WGC HMU was designed to be physically and functionally interchangeable with a Hamilton Standard Division (HSD) HMU. Although there are internal and

external differences between the two units, the WGC HMU was designed to provide the same fuel flow and respond to engine input signals in the same manner as a HSD HMU. Two versions of the WGC HMU were tested: an "interim" model and a "production" model. The "interim" model incorporated five of the six planned modifications and was used to expedite commencement of AEFA flight tests. The "production" model incorporated all six modifications. Except where noted otherwise. the phrase "WGC HMU" refers to the production version WGC HMU. A more detailed description of the WGC HMU and its modifications is contained in appendix B.

6. The test aircraft. U.S. Army S/N 88-26015, is a twelfth year production UH-60A Black Hawk helicopter. Changes to the test aircraft included a modification to the engine speed control system that extended the allowable speed range from 96%-100% Np to 94%-102% Np, an instrumentation package, and an airspeed boom. A portable oxygen system was installed for flights above 10,000 ft pressure altitude. A more detailed description of the UH-60A is contained in the Prime Item Development Specification (ref 2) and the operator's manual (ref 3).

TEST SCOPE

7. The Preliminary Airworthiness Evaluation of the WGC HMU was conducted in accordance with the approved test plan (ref 4) at the specific mission maneuvers and engineering tests listed in table 1. Testing was conducted at Edwards AFB, California (elevation 2302 feet) and Coyote Flat, California (elevation 9980 feet) from 14 May 1989 to 14 June 1989. Eleven flights were conducted for a total of 15.5 productive flight hours. Tests were conducted at an average gross weight of 14,200 pounds, an average longitudinal center of gravity of 356.2 inches (mid), and altitudes ranging from field elevation to 20,000 ft pressure altitude. Flight restrictions and operating limitations observed during the evaluation are contained in the operator's manual (ref 3) and in the airworthiness release (ref 5). Four configurations, each incorporating a different combination of HSD/WGC HMUs installed on the aircraft engines, were used for this evaluation. The four test configurations are listed in table 2.

Table 1. Test Conditions[1]

Test		HMU[2] Test Configuration	Pressure Altitude (ft)	Indicated Airspeed (kts)
Ground Evaluations	Installation Procedures	1, 2, 3, 4	Field Elevation[5]	0
	EPCL[3] Mechanical Characteristics			
	Engine Starts[4]			
	Engine Trim Response			
	Isochronous Governing Characteristics			
	Engine Shutdown			
Engine Restarts in Flight		1, 2 1, 3, 4 1, 3, 4 1, 3	4860 - 5340 10080 - 10390 14720 - 15330 19180 - 19960	54 - 94 67 - 118 59 - 66 41 - 64
Engine Airframe Response	Jump Takeoff	1, 2	Field elevation to 3230	0
	Quick Stop	1, 2, 4	2470 to field elevation	133 - 0
	Button Hook	1, 2	2690 to field elevation	135 - 0
	Ridgeline Crossing		2500 - 3150	85, 126 - 133
	Bullwhip	1 1, 3 1, 3, 4 1, 3	4780 - 4920 10260 - 10470 15050 - 15350 20000	117 - 126 73 and 131 63 and 114 54
	Power Recoveries from Autorotation	1, 2 1, 3 1, 3	4340 - 5150 9200 - 10690 14950 - 16660	85 - 118 70 - 100 65 - 83
Engine Drive Train Stability	Recovery from Simulated Engine Failure	1, 2 1, 4 1, 3, 4 1, 3	4160 - 6490 10220 - 11670 15100 - 15930 19010 - 19930	87 - 118 81 - 112 62 - 79 55 - 63
	Level Turns	1 1, 2, 3, 4 1, 3, 4 1, 3	4970 - 5410 9870 - 10260 15000 - 15180 19690 - 20000	100 - 115 58 - 110 64 - 100 59 - 70
	Collective Fixed Turn	1 1, 3, 4	5590 - 7280 8340 - 12190	128 - 142 80 - 130
	Collective Response	1, 3, 4	10200 - 10480 14940 - 15330	129 - 133 100 - 110
ECU[6] Lockout		1, 4 1, 3, 4 1, 3, 4 1, 3	Field elevation 9710 - 12220 14990 - 15300 19590 - 20000	0 72 - 109 62 - 90 46 - 55

NOTES:

[1]Unless otherwise noted, tests were conducted at a takeoff gross weight of approximately 15,000 lb and a mid center of gravity in ball-centered flight. Doors and windows were closed, AFCS ON, engine bleed systems OFF and main rotor speed set at 100%. Oxygen requirements, as stated in AR 95-1, were observed.
[2]HMU: Hydromechanical Unit. Test configuration description (see table 2).
[3]EPCL: Engine Power Control Lever.
[4]Also conducted at Coyote Flat, CA (field elevation 9980 feet), configuration 4.
[5]Conducted at Edwards AFB, CA (field elevation 2302 feet).
[6]ECU: Electrical Control Unit.

Table 2. Test Configurations

Configuration Numbers	Engine #1 HMU		Engine #2 HMU	
1	Hamilton Standard	(UDAJ5284)[1]	Interim Woodward	(WYG54238)
2	Interim Woodward	(WYG54250)	Interim Woodward	(WYG54238)
3	Production Woodward	(WYG54243)	Interim Woodward	(WYG54238)
4	Production Woodward	(WYG54243)	Hamilton Standard	(UDAJ5284)

NOTE:

[1]HMU serial number.

TEST METHODOLOGY

8. Flight test data were obtained from calibrated test instrumentation and recorded on magnetic tape installed in the aircraft. Real time telemetry was used to monitor selected parameters throughout the test. A detailed listing of test instrumentation is contained in appendix C. Test techniques are described in appendix D.

RESULTS AND DISCUSSION

GENERAL

9. A Preliminary Airworthiness Evaluation of the Woodward Governor Company (WGC) Hydromechanical Unit (HMU) installed on T700-GE-700 engines was conducted. The acronym WGC will refer to the production model WGC HMU unless otherwise specified. Two models of Woodward HMU's were tested: an interim WGC HMU and the WGC HMU. The only difference between the interim WGC HMU and the WGC HMU was the isochronous governing (downtrim) characteristic. Uncommanded static downtrim of the interim WGC HMU occurred during a flat pitch, high ambient temperature condition following the disengagement of the opposing engine. The majority of testing conducted during this evaluation is independent of the WGC HMU model and data with the interim WGC HMU is valid and representative of the WGC HMU. Performance of Hamilton Standard Division (HSD) and WGC HMUs was similar. Operation of T700-GE-700 engines with WGC HMUs installed is satisfactory except that the poor engine/rotor transient droop characteristics identified in previous U.S. Army Aviation Engineering Flight Activity (AEFA) UH-60A evaluations (ref 6 and 7, app A) remain a shortcoming regardless of the HMU installed.

INSTALLATION PROCEDURES

10. Installation procedures of the WGC HMU on T700-GE-700 engines were qualitatively evaluated to determine if the WGC HMU could be installed using the existing HMU installation procedures outlined in TM 55-2840-248-23 (ref 8). Installation of the WGC HMU differs only slightly from the HSD HMU. During installation of the HSD HMU, if the splines on the HMU drive shaft do not align with the splines in the accessory gear box (AGB), the drive shaft can be rotated by hand. The drive shaft on the WGC HMU, however, cannot be turned by hand. The break-away torque for the WGC HMU drive shaft is 24 inch pounds as compared to 0.37 inch pounds needed to turn the HSD HMU drive shaft. The difference in breakaway torque is insignificant when the system is pressurized.

11. To align the splines, the radial drive shaft assembly was accessed through the Axis-A cover on top of the AGB and turned. This rotated the AGB mating spline. An alternative procedure is to align the drive shaft of the WGC HMU by rotating the HMU as a unit about the drive shaft until the HMU splines are aligned with the AGB splines. After mating the splines, the HMU can be rotated back into position for installation. To avoid difficulties during HMU installation, the following NOTE should be incorporated after paragraph 6-50(e) "Installation of Hydromechanical Control Unit (HMU) and Grooved Clamp Coupling" of the maintenance manual (ref 8).

NOTE

When installing a Woodward Governor Company HMU, the splines of the AGB and HMU may not align. To align the splines, access the radial drive shaft assembly through the Axis-A cover on top of the AGB and turn the radial drive shaft to rotate the AGB mating spline. An alternate procedure: align the drive shaft by rotating the entire HMU about the drive shaft, mate with the splines of the AGB, and rotate the entire HMU back into position for completion of installation.

MECHANICAL CHARACTERISTICS

12. Engine Power Control Lever (EPCL) mechanical characteristics were qualitatively evaluated, to determine if noticeable control force differences existed between EPCLs connected to HSD HMUs and EPCLs connected to WGC HMUs. The EPCLs were moved individually and simultaneously. EPCL movement forward, from IDLE to FLY, or rearward, from FLY to IDLE, was performed at various rates ranging from approximately one to five seconds. The force required for rapid (less than one second) individual EPCL movement was perceptibly less when the EPCL being moved was connected to a WGC HMU. However, during dual EPCL movement, there was no tendency for one EPCL to lead or lag the other. The mechanical characteristics of EPCLs connected to WGC HMUs are satisfactory.

ENGINE START CHARACTERISTICS

13. Engine ground starts using Auxiliary Power Unit (APU) and crossbleed procedures as outlined in the operator's manual (ref 3) were evaluated at field elevations of 2302 ft and 9980 ft. Time histories of engine starts using the APU as an air source with a HSD and a WGC HMU installed are shown in figures E-1 and E-2 respectively. During single and dual engine starts, engine parameters were essentially the same regardless of the HMU installed on the engine being started. The performance of the WGC HMU during engine ground starts using the APU and crossbleed start sequence of the T700-GE-700 engine is satisfactory.

ENGINE RESTARTS IN FLIGHT

14. Engine restarts in flight, using the APU and engine crossbleed procedures outlined in the operator's manual (ref 3), were completed at pressure altitudes ranging from 4860 ft to 19,960 ft at increments of approximately 5000 ft. Data are presented in table 3. Time histories of engine restarts above 19,000 ft pressure altitude using the APU as an air source with a HSD and WGC HMU installed are presented in figures E-3 and E-4, respectively. During APU and crossbleed starts, engine parameters were essentially the same regardless of the HMU installed on the engine being started. In-flight engine restart characteristics of T700-GE-700 engines with WGC HMUs installed are satisfactory.

Table 3. Engine Restarts In Flight

Pressure Altitude (ft)	Starting Engine/ HMU[1] Installed	Air Source	Minimum TGT[2] Prior to Start (°C)	Maximum TGT (°C)	Time to Maximum TGT (sec)[3]	Steady State Ng[4] (%)	Time to Steady State Ng (sec)[3]	Starter Engagement Time (sec)	Remarks
5,110	#1/HSD[5]	APU[6]	150	690	21	66	22	33	
5,090	#2/WGC.I[7]	APU	145	660	22	64	22	35	
4,860	#1/WGC[8]	Cross Bleed	145	660	22	68	23	40	Eng #2 W/WGC HMU
10,160	#2/WGC.I	APU	150	660	26	67	28	50	
10,080	#1/HSD	Cross Bleed	145	670	23	68	23	45	Eng #2 W/WGC HMU
10,110	#1/WGC	Cross Bleed	150	640	27	68	27	31	Eng #2 W/WGC HMU
15,080	#1/HSD	APU	140	675	28	67	32	57	
15,250	#1/WGC	APU	150	690	18	68	35	63	
14,720	#1/HSD	Cross Bleed	145	660	24	68	27	50	Eng #2 W/WGC HMU
15,330	#1/WGC	Cross Bleed	110	605	27	68	29	44	Eng #2 W/WGC HMU
19,350	#1/HSD	APU	150	805	23	68	40	72	
19,180	#1/WGC	APU	145	790	23	67	45	69	
19,600	#1/HSD	Cross Bleed	150	750	21	64	35	70	Eng #2 W/WGC HMU
19,960	#1/WGC	Cross Bleed	150	840	27	65	49	101	Eng #2 W/WGC HMU

NOTES:

[1]HMU: Hydromechanical unit.
[2]TGT: Turbine gas temperature.
[3]Time started when engine power control lever was placed in IDLE position.
[4]Ng: Gas generator speed.
[5]HSD: Hamilton Standard Division.
[6]APU: Auxiliary power unit.
[7]WGC.I: Woodward Governor Company, interim model.
[8]WGC: Woodward Governor Company, production model.

ENGINE TRIM RESPONSE

15. Engine trim response tests were conducted to determine the difference between trim response rates of HSD HMUs and WCG HMUs. A representative time history of the trim response of an interim WGC HMU is presented in figure E-5. The engine trim response rate of the HSD HMU and the WGC HMU was similar. The engine trim response rate of the WGC HMU is satisfactory.

ISOCHRONOUS GOVERNING CHARACTERISTICS

16. Isochronous governing characteristics of the WGC HMU were evaluated to determine if uncommanded static Nr droop (down trim) occurred during flat pitch on the ground, high ambient temperature conditions following the disengagement of the opposing engine. The test technique is described in appendix D. Representative time histories of interim and production WGC HMUs are presented in figures E-6 and E-7, respectively. The interim WGC HMU (no load demand spindle (LDS) cam modification) allowed an uncommanded droop of main rotor RPM from 100% to 98% at an ambient temperature of +36° C. The production WGC HMU (with LDS cam modification incorporated) allowed no static droop of main rotor RPM at an ambient temperature of +36° C. HSD and WGC HMU isochronous governing during flat pitch on the ground, high ambient temperature conditions following the disengagement of the opposing engine was similar. The isochronous governing characteristic of WGC HMUs during single engine, flat pitch on the ground, high ambient temperature conditions is satisfactory.

ENGINE/AIRFRAME RESPONSE

17. Engine/airframe response tests consisted of jump takeoffs, quickstops, button hooks, ridgeline crossing maneuvers, bullwhip maneuvers, and power recoveries from autorotation. The test techniques and maneuvers are described in appendix D. Representative time histories are presented in figures E-8 through E-13. Power turbine/main rotor (Np/Nr) droop recovery and Np governing characteristics were similar for all HMU configurations. The most severe transient Nr droop (to 79%) occurred during a power recovery from autorotation with a Np/Nr split of 10% (figure E-13). The collective was increased from 0.6 in. (the collective position required to maintain the 10% Np/Nr split) to 9.4 in. (95% intermedated rated power (IRP)) in 2.5 seconds. Previous AEFA UH-60A evaluations (ref 6 and 7) identified poor transient droop characteristics during maneuvers requiring rapid power applications from low torque settings as a shortcoming. The previous evaluations were conducted with HSD HMUs installed on both engines. During this evaluation, poor engine/rotor transient droop characteristics were noted with either WGC or HSD HMU's installed and remain a shortcoming.

ENGINE/DRIVE TRAIN STABILITY

18. Engine/drive train stability tests consisted of recoveries from simulated single engine failures, collective pulse inputs during level turns, collective fixed turns, and collective response. The test techniques and maneuvers are described in appendix D. Representative time histories are presented in figures E-14 through E-18. The engine/drive train response for all configurations tested was well damped. The engine/drive train stability of T700-GE-700 engines with the WGC HMU installed is satisfactory.

ELECTRICAL CONTROL UNIT (ECU) LOCKOUT

19. Engine response while operating in ECU lockout was evaluated. The ECU lockout procedures outlined in the operator's manual (ref 3) were utilized. Performance of T700-GE-700 engines during ECU lockout operations with HSD and/or WGC HMUs installed was similar. The performance of T700-GE-700 engines during ECU lockout operations with WGC HMUs installed is satisfactory.

ENGINE SHUTDOWN

20. Engine shutdown characteristics of T700-GE-700 engines with WGC HMUs installed were evaluated to determine if gas generator speed (Ng) could be stabilized at speeds below IDLE (sub-idle fuel flow modulation). Representative time histories are presented in figures E-19 and E-20. During shutdown of an engine with a HSD HMU installed (Fig. 19), all engine parameters (TGT, Ng, fuel pressure, and fuel flow rate) remained at IDLE values until the EPCL reached approximately 10% of full travel (13% aft of the idle stop). Further movement of the EPCL toward the OFF position caused an immediate decrease of engine parameters, indicating fuel flow had been stopcocked. Minimum Ng prior to stopcock was 68%. Similar results were observed during shutdown of an engine with an interim WGC HMU installed (Fig. 20) and no sub-idle fuel flow modulation was noted. Engine shutdown characteristics of T700-GE-700 engines with WGC HMUs installed are satisfactory.

ENGINE FLAMEOUT CONDITIONS

21. A total of four flameouts occurred during the evaluation. Two flameouts occurred during engine/airframe response testing and two occurred during engine/drive train stability testing. A summary of flameout conditions are listed in table 4.

Table 4. Engine Flameout Conditions

Configuration	Failed Engine	Altitude (ft)	OAT[1] GND (°C)	OAT[2] ALT (°C)	Maneuver	HMU[3]	Boost Pumps
1	2	14,100	22	-2.0	#2 EPCL IDLE to FLY in three seconds	Interim WGC[4]	OFF
3	2	15,300	18	-5.5	#2 EPCL IDLE to FLY in three seconds	Interim WGC	OFF
4	1	15,000	21	-0.5	Bullwhip	Production WGC	OFF
4	2	16,600	21	-2.0	Power Recovery from Autorotation	HSD[5]	OFF

NOTES:

[1]OAT GND: Outside air temperature on ground.
[2]OAT ALT: Outside air temperature at altitude.
[3]HMU: Hydromechanical Unit.
[4]WGC: Woodward Governor Company.
[5]HSD: Hamilton Standard Division.

Conditions common to all flameouts were less than 650 lb total fuel remaining, fuel temperature above 70°F, and fuel boost pumps OFF. All engine failures were preceeded by illumination of the FUEL PRESS caution light for the appropriate engine followed immediately by engine flameout. The flameouts could not be duplicated when the engine fuel boost pumps were ON and operational. The flameouts were attributed to misinterpretation of the operator's manual concerning use of the fuel boost pumps. Paragraph 5–18 of the operator's manual (ref 3) lists combinations of pressure altitudes and ambient temperatures above which both fuel boost pumps are required to be ON and operational. Project pilots interpreted "ambient temperature" to be the ambient temperature at the flight altitude. The Department of Evaluation and Standardization at the U.S. Army Aviation Center, Fort Rucker, Alabama, confirmed that the same interpretation is being taught at the UH–60A Aircraft Qualification Course. Representatives from General Electric Company maintained that "ambient temperature" referred to ambient temperature at ground level at the time of takeoff. Using the latter interpretation, both fuel boost pumps should have been ON and operational when the flameouts occurred. The following change should be made to paragraph 5-18a of the operator's manual (ref 3):

a. When operating with JP-4 fuel, both fuel boost pumps shall be ON and operational under the following conditions:

WHEN FLIGHT IS CONDUCTED AT A PRESSURE ALTITUDE OF:	AND, AMBIENT TEMPERATURE AT TIME AND LOCATION OF TAKEOFF IS AT OR ABOVE:
Sea level to 2,000 feet	+35°C (+95°F)
2,000 to 10,000 feet	+30°C (+86°F)
Above 10,000 feet	+15°C (+59°F)

CONCLUSIONS

GENERAL

22. Performance of Hamilton Standard Division and Woodward Governor Company Hydromechanical Units was similar. Operation of T700-GE-700 engines with Woodward Governor Company Hydromechanical Units installed is satisfactory except for one previously identified shortcoming (para 17).

SHORTCOMING

23. The following previously identified shortcoming was noted and is independent of the Woodward Governor Company or Hamilton Standard Division Hydromechanical Unit installation.

a. The poor transient droop characteristics during maneuvers requiring rapid power applications from low torque settings (para 17).

RECOMMENDATIONS

24. The shortcoming described in paragraph 17 should be corrected.

25. The following **NOTE** should be incorporated after paragraph 6–50(e) "Installation of Hydromechanical Control Unit (HMU) and Grooved Clamp Coupling" of the maintenance manual (ref 8) (Para 10).

NOTE

> When installing a Woodward Governor Company HMU, the splines of the accessory gearbox (AGB) and HMU may not align. To align the splines, access the radial drive shaft assembly through the Axis–A cover on top of the AGB and turn the radial drive shaft to rotate the AGB mating spline. An alternate procedure: align the drive shaft by rotating the entire HMU about the drive shaft, mate with the splines of the AGB, and rotate the entire HMU back into position for completion of installation.

26. The following change should be made to paragraph 5-18a of the operator's manual (ref 3) (para 21).

a. When operating with JP-4 fuel, both fuel boost pumps shall be ON and operational under the following conditions:

WHEN FLIGHT IS CONDUCTED AT A PRESSURE ALTITUDE OF:	AND, AMBIENT TEMPERATURE AT TIME AND LOCATION OF TAKEOFF IS AT OR ABOVE:
Sea level to 2,000 feet	+35°C (+95°F)
2,000 to 10,000 feet	+30°C (+86°F)
Above 10,000 feet	+15°C (+59°F)

APPENDIX A. REFERENCES

1. Memorandum, AVSCOM, AMSAV-8, 19 April 1989, subject: Test Request, Preliminary Airworthiness Evaluation (PAE) of the Woodward Hydro-Mechanical Unit Installed on the T700-GE-700 Engines in the UH-60A Helicopter, Project No. 89-14.

2. Prime Item Development Specification, Sikorsky Aircraft Division, DARCOM CP-2222-S1000 H, 11 December 1987.

3. Technical Manual, TM 55-1520-237-10, *Operator's Manual, UH-60A Helicopter*, 8 January 1988 with change 3 dated 12 August 1988.

4. Memorandum, AEFA, SAVTE-TI, 25 April 1989, subject: Test Plan, Preliminary Airworthiness Evaluation (PAE) of the Woodward Hydromechanical Unit (HMU) Installed on T700-GE-700 Engines in the UH-60A Helicopter, AEFA Project No. 89-14.

5. Memorandum, AVSCOM, AMSAV-8, 2 May 1989, subject: Airworthiness Release for UH-60A Black Hawk Helicopter S/N 88-26015 to Conduct a Preliminary Airworthiness Evaluation (PAE) of the WGC Hydromechanical Unit (HMU) Installed on the T700-GE-700 Engines.

6. Letter, USAAEFA, DAVTE-TB, 26 April 1979, Subject: Preliminary Airworthiness Evaluation (PAE) III, UH-60A Black Hawk Helicopter, USAAEFA Project No. 78-22.

7. Final Report, USAAEFA, Project No. 77-17, *Airworthiness and Flight Characteristics Evaluation UH-60A (Black Hawk) Helicopter*, September 1981.

8. Technical Manual, TM-55-2840-248-23, *Aviation Unit and Intermediate Maintenance Instructions, Engine, Aircraft, Turboshaft, Model T700-GE-700*, 28 April 1982 with change 15 dated 12 April 1989.

APPENDIX B. DESCRIPTION

GENERAL

1. The Sikorsky UH-60A Black Hawk helicopter used for this evaluation, U.S. Army S/N 88-26015, is a twelfth year production aircraft. The power plants for the UH-60A helicopter are General Electric T700-GE-700 turboshaft engines. Metering of fuel to the engine and basic engine control computations are performed in the Hydromechanical Unit (HMU). Computations which determine the exact quantity of fuel to be scheduled to the engine to satisfy power requirements are performed in both the Electrical Control Unit (ECU) and the HMU.

ELECTRICAL CONTROL UNIT

2. The ECU performs HMU trimming of gas generator speed (Ng) governor as determined by the following:

a. Isochronous power turbine speed (Np) governing
b. Turbine gas temperature (TGT) limiting
c. Load sharing on torque
d. N_p reference input from cockpit

Additional features of the ECU are: redundant N_p overspeed limit, cockpit signal generation to N_p, TGT, torque, and recorder power and signal supply.

HYDROMECHANICAL UNIT

3. The HMU, mounted on the aft center of the accessory gear box, provides fuel pumping, fuel metering, fuel flow computation, fuel pressurization, and fuel shutoff (figs. B-1 and B-2). It also provides Ng control, compressor variable geometry scheduling and actuation, and anti-icing and starting bleed valve actuation. The unit responds to power available spindle (PAS) input for fuel shutoff, start, ground idle, to set maximum permissible Ng, vapor venting, and to provide for an ECU override capability. The HMU also responds to an externally supplied load demand input via the load demand spindle (LDS). This initially and directly coordinates Ng and power to approximate the power required by the rotor. The HMU then responds to input from an ECU via the HMU torque motor, to precisely trim Ng as directed for both Np control and TGT limiting for more exact load share control. The HMU also has the capability to mechanically deactivate the ECU in the event of an ECU failure and vent the unit case to overboard drain in the event of excessive air or vapor at the inlet by use of overtravel in the PAS. The HMU responds to sensed engine parameters which influence fuel flow and variable geometry position. The basic control and governing functions of the HMU are outlined as follows:

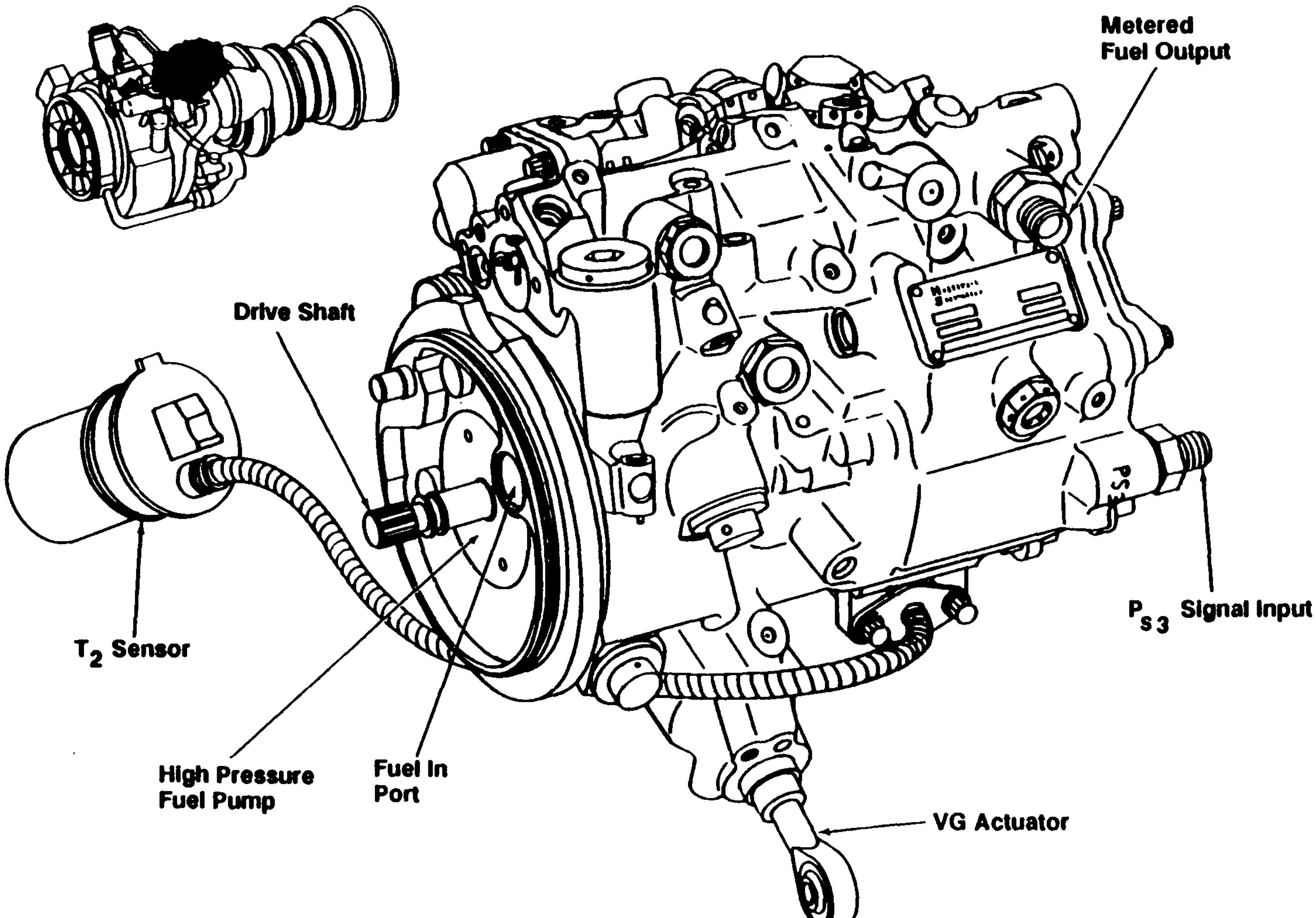


Figure. B-1. Hydromechanical Unit

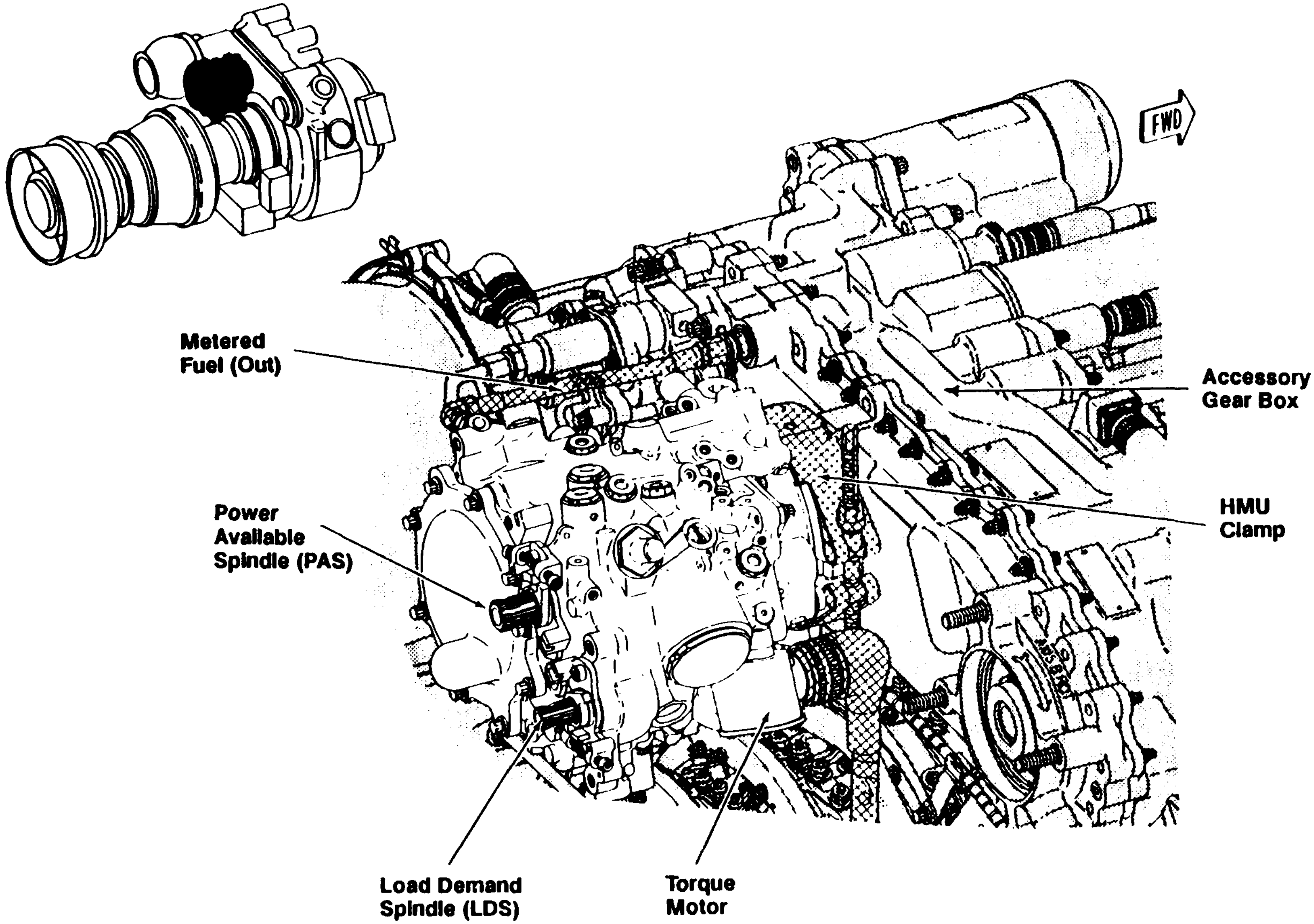


Figure B-2. Hydromechanical Unit-Right Rear

- Fuel Pumping
- Fuel Flow Metering
- Acceleration and Deceleration Flow Limiting (as a function of $\frac{W_F}{P_3}$, N_g, and T_2)
- N_g Limiting
- Variable Geometry Positioning (as a function of $N_g/\sqrt{\theta}$)
- ECU Signal Acceptance (through torque motor, to trim N_g governor)
- Starting Fuel Scheduling
- Collective Compensation through LDS Angle
- ECU Lockout Function through PAS Angle
- PAS Control with ECU Inoperative

A functional block diagram is presented in figure B-3.

4. The Woodward Governor Company (WGC) HMU was designed to be physically and functionally interchangeable with the Hamilton Standard Division (HSD) HMU. Figures B-4 and B-5 show the external differences between the HSD and WGC HMU. There are also internal differences as described in table B-1.

Table B-1. Internal Differences

Component	HSD HMU	WGC HMU
Main Pump	Vane Pump	Gear Pump
Metering	Axial Positioned Valve	Axial and Rotational Valve
PS3 System	Multiplying Servo	Direct Acting
T2 System	Bulb to Mechanical Linkage	Bulb to Servoed Actuator
By-pass Valve	Spring Actuated with Fuel Temp Comparison	Spring Actuated
Minimum Flow Regulator	Fixed Stop on Main Metering	Regulator Valve
3-D Cams	One Cam for Both Acceleration/Governing	Two Cams
Parts Count	1200	939

5. Time constraints dictated the use of two versions of the WGC HMU. An "interim" model, which incorporated modifications 1 through 5 to an original prototype HMU is described in table B-2. This was initially used to expedite commencement of AEFA flight tests. The "production" model incorporated all six modifications (table B-2) and was used for all tests subsequent to its availability.

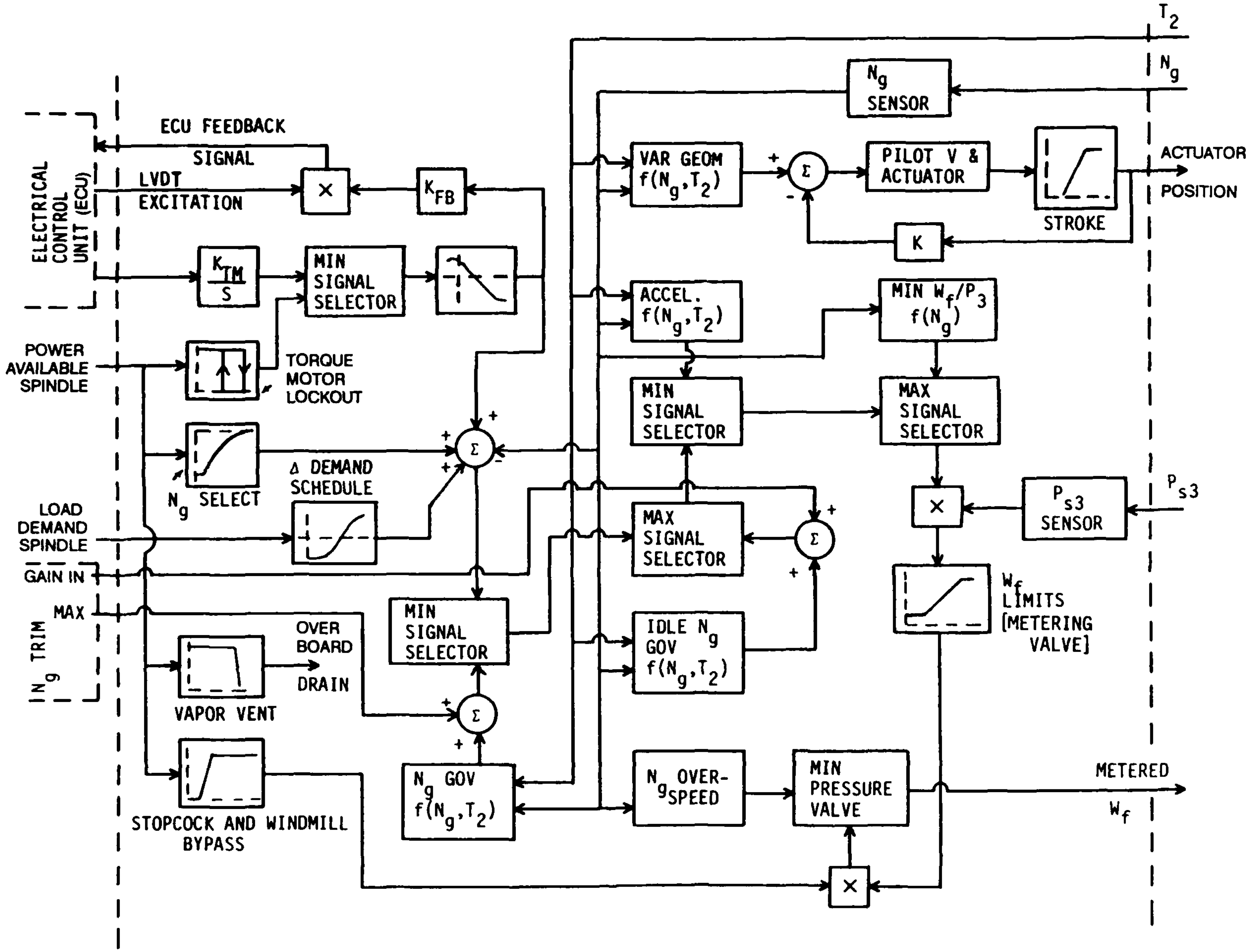


Figure B-3. Hydromechanical Unit Functional Block Diagram

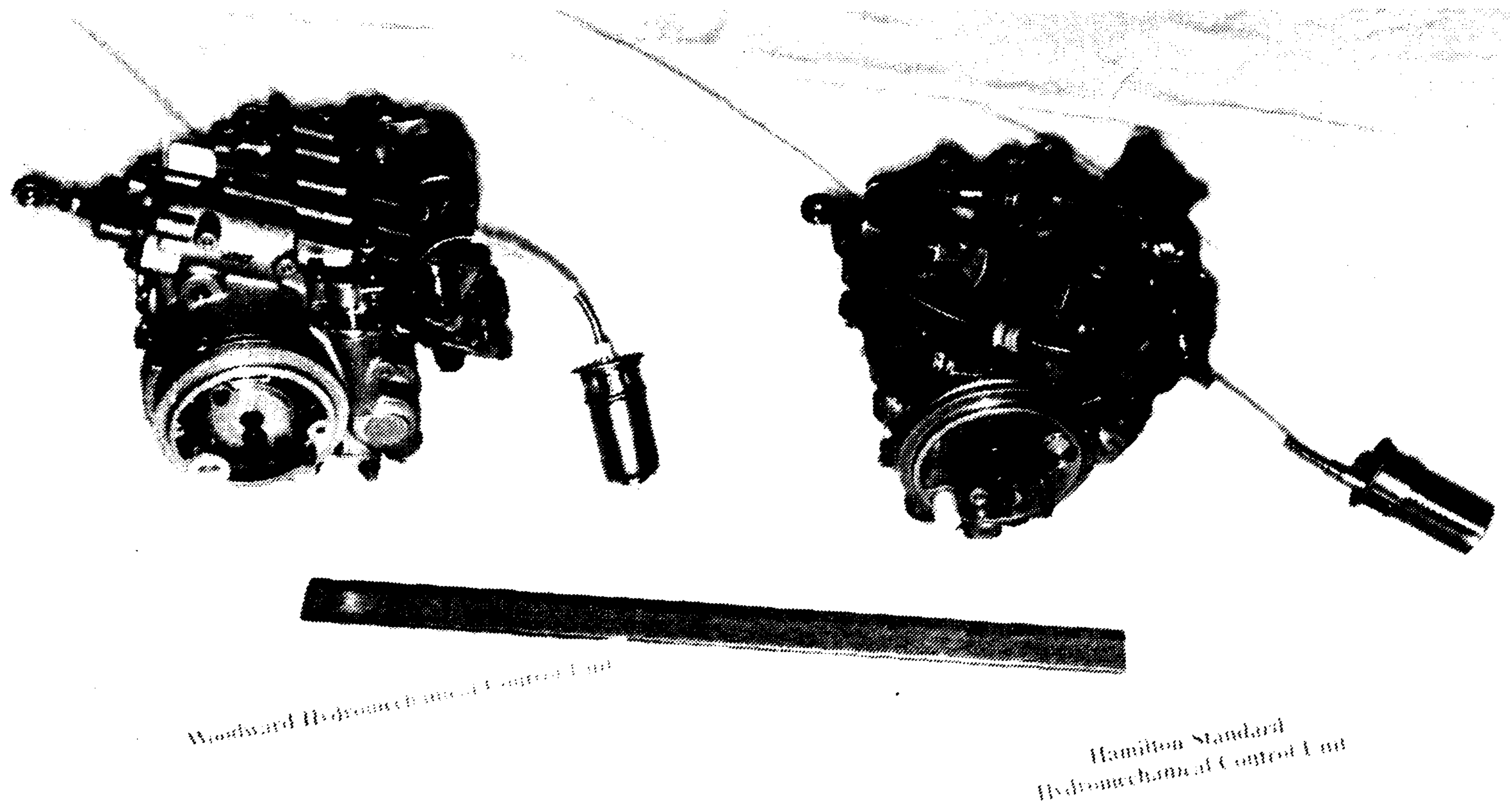


Figure B-4. Hydromechanical Unit – Forward View

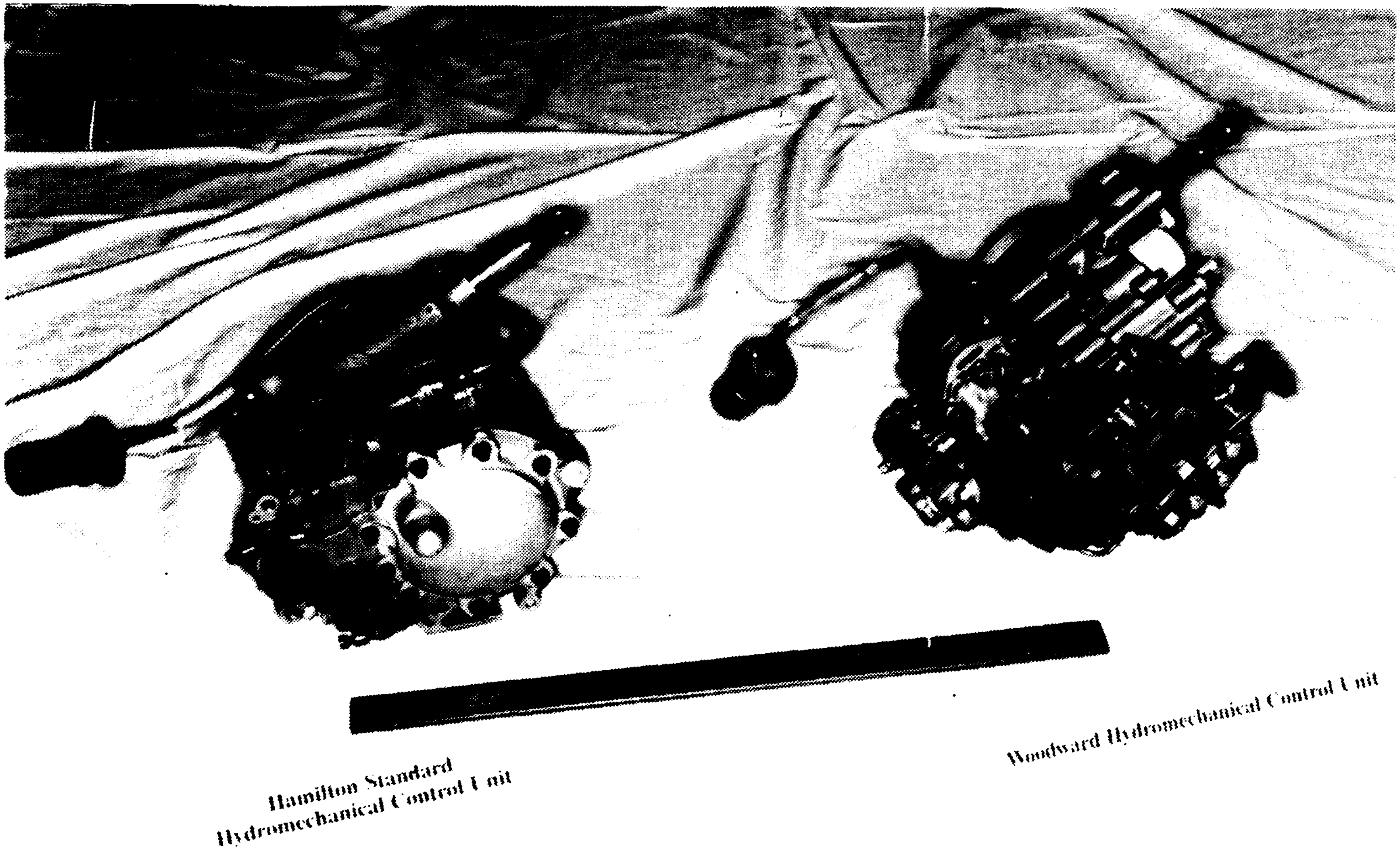


Figure B-5. Hydromechanical Unit – Aft View

Table B-2. Modifications

Modification Number	Description
1	Painted scribe line to enhance max travel rigging
2	Cover plate clearance modification to resolve PAS/LDS actuator interference problem
3	Increased PAS torque to resolve uncommanded PAS motoring
4	Removal of Lee directional flow control valve to correct sub-idle fuel flow modulation problem
5	Modification of HMU pressurizing and bypass valve to correct low power flameouts caused by fuel flow oscillations at low fuel flow rates
6	LDS cam modification to correct N_P/N_R down trim and up trim problem

APPENDIX C. INSTRUMENTATION

GENERAL

1. The airborne data acquisition system was installed, operated and maintained by the U.S. Army Aviation Engineering Flight Activity. The data acquisition system utilized pulse code modulation (PCM) encoding. Sampling rate was 454 samples/second for mainframe while subframe sample rate varied from 28 to 114 samples/second. Data was obtained from telemetry, calibrated cockpit instruments or recorded on magnetic tape.

2. A boom, extending forward from the nose of the aircraft, was used and incorporated angle-of-attack and angle-of-sideslip sensors, and a swiveling pitot-static tube.

3. Data displayed on board the aircraft include the following.

Pilot Station

Airspeed (boom)
Altitude (boom)
Altitude*
Rotor speed*
Engine torque* **
Turbine gas temperature (TGT)* **
Engine gas generator speed* **
Collective position
Normal acceleration indicator

Copilot Station

Airspeed*
Total air temperature*

Engineer Panel

Engine fuel used**
Auxiliary power unit fuel used
Total air temperature
Time code display
Run number
Event
Instrumentation control

4. Parameters recorded on board the aircraft and via telemetry include the following. Instrumentation installed to monitor the hydromechanical unit (HMU) is depicted in figure C-1.

*Noncalibrated ship's system
**Both engines

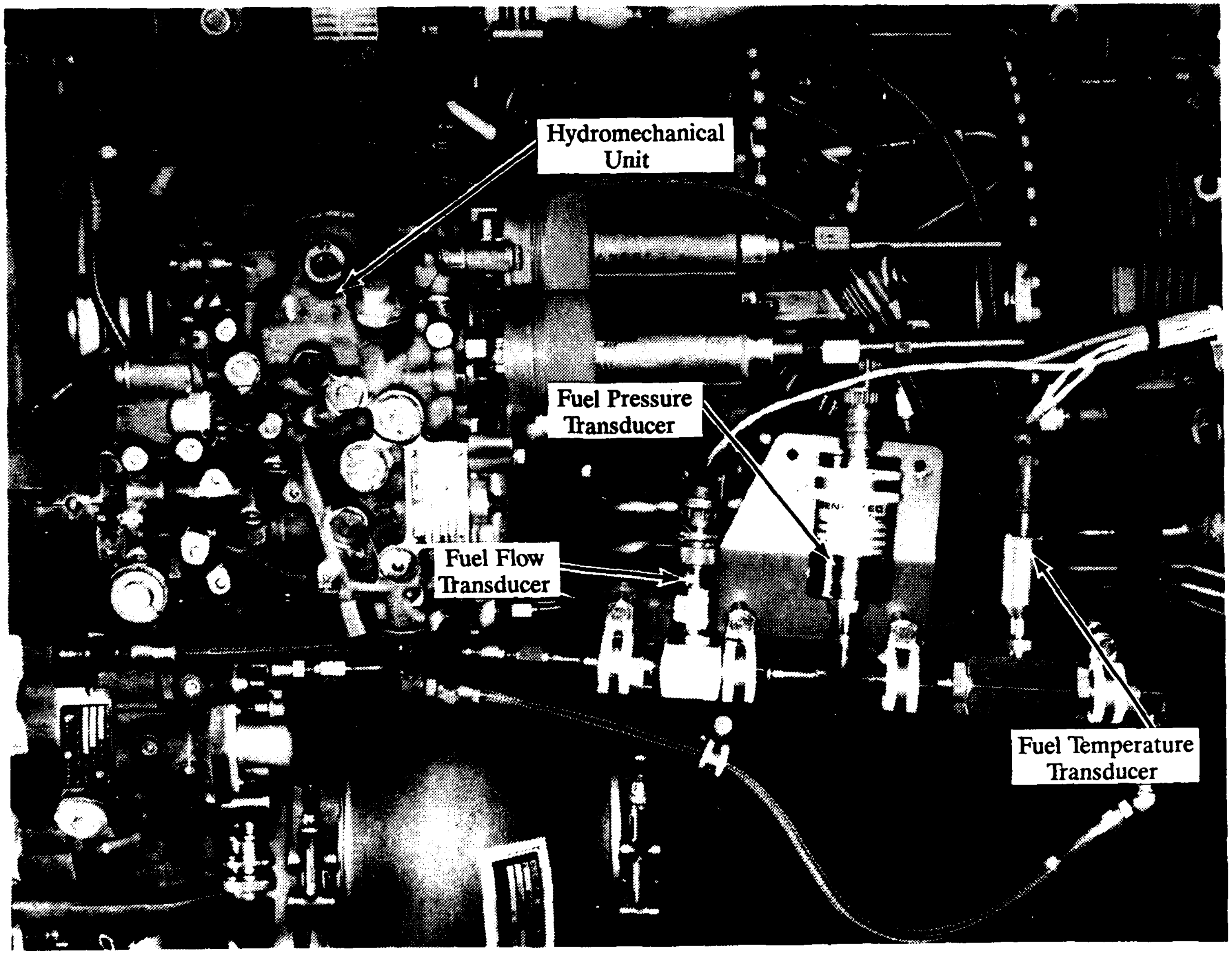


Figure C-1. Hydromechanical Unit Assembly

Digital (PCM) Parameters

Airspeed (boom)
Airspeed (ship)
Altitude (boom)
Altitude (ship)
Total air temperature
Rotor speed
Engine gas generator speed (Ng)**
Engine power turbine speed (N_P)**
Engine measured gas temperature**
Engine torque**
Tail rotor shaft torque
Compressor discharge pressure**
Control Positions
    Longitudinal
    Lateral
    Collective
    Pedal
    Engine Power Control Lever**
HMU discharge fuel pressure **
HMU discharge fuel flow **
HMU discharge fuel temperature **
Starter motor air static pressure **
Attitude
    Pitch
    Roll
Center of gravity normal acceleration
Run number
Time code

*Noncalibrated ship's system
**Both engines

APPENDIX D. TEST TECHNIQUES

GENERAL

1. All test data were obtained from test instrumentation and recorded on magnetic tape installed in the aircraft. Reduced data were presented as time histories and analyzed for engine response.

ISOCHRONOUS GOVERNING CHARACTERISTICS

2. The tests were initiated by positioning both Engine Power Control Lever (EPCLs) at FLY and setting main rotor RPM (N_R) at 100% using the pilot's ENG RPM control switch. The EPCL of the engine to be tested remained at FLY and the opposite EPCL was retarded to IDLE. Main rotor RPM was monitored for static changes from the initial setting.

ENGINE TRIM RESPONSE

3. Engine trim response was evaluated by positioning the EPCL for the engine to be tested at FLY and the opposite EPCL at IDLE. N_R was set at 95% using the ENG RPM control switch on the pilot's collective stick grip. The ENG RPM control switch was then held in the INC position until maximum attainable N_R was achieved. The data recording system was turned on prior to moving the ENG RPM control switch to the INC position and remained on until maximum attainable Nr was achieved and had stabilized.

JUMP TAKEOFFS

4. Jump takeoffs were accomplished by making a ramp collective input from a light on wheels collective setting and from a flat pitch collective setting to 95% of Intermediate Rated Power (IRP). Five second and two second collective pulls were evaluated. The data recording system was turned on when the collective was set at the flat pitch or light on wheels setting and remained on until the vertical rate of climb stabilized.

QUICKSTOPS

5. Quickstops were initiated from 120 knots indicated airspeed (KIAS), level flight, at 50 ft above ground level (AGL). The aircraft was decelerated by simultaneously reducing collective to full down and applying aft cyclic. As the ground speed neared zero, the aircraft attitude was rapidly leveled using forward cyclic prior to increasing collective to maintain constant altitude. The data recording system was turned on when the aircraft was stabilized at 120 KIAS, level flight, and remained on until the maneuver was terminated and engine parameters had stabilized.

BUTTON HOOK

6. The button hook was initiated from 120 KIAS, 400 ft AGL, at a point abeam the intended touchdown area. The collective was reduced to the full down position and right, aft cyclic was applied to start a right, descending, decelerating, autorotative 180° turn. After 180° of turn, the aircraft was rapidly brought to wings level using left lateral cyclic and collective was increased to control the rate of descent. The data recording system was turned on when the aircraft was abeam the intended touchdown area and remained on until the maneuver was terminated at a stable hover over the intended touchdown area and the Np/Nr response had stabilized.

RIDGELINE CROSSING

7. Ridgeline crossing maneuvers were performed at 120 KIAS and 100 ft AGL by applying aft cyclic and increasing collective to achieve a load factor of approximately +2.0, followed immediately by application of forward cyclic and reduction of collective to achieve a load factor of approximately +0.5. When the N_P/N_R peaked during the descent, collective was rapidly increased to return the aircraft to level flight. The data recording system was turned on when the aircraft was stabilized at 120 KIAS, level flight and remained on until the aircraft was reestablished at level flight and the N_P/N_R response had stabilized.

BULLWHIP MANEUVER

8. The bullwhip maneuver was accomplished by reducing the collective slowly from the level flight setting until the anti-ice lights illuminated followed by rapidly increasing the collective to 95% IRP. The collective was cycled down and up twice and then held at 95% IRP. The data recording system was turned on just prior to initial collective reduction and remained on until engine parameters had stabilized following cycling of the collective.

POWER RECOVERIES FROM AUTOROTATION

9. Power recoveries from autorotations were initiated from an autorotative descent at 80 KIAS. Differences between power turbine speed and main rotor RPM (N_P/N_R split) of 0%, 5%, and 10% were evaluated. Recovery was accomplished by increasing collective to 95% IRP at rates of ten, five, and two seconds. The data recording system was turned on after a stable autorotative descent was established at the desired N_P/N_R split and remained on until engine parameters stabilized following the collective increase.

RECOVERIES FROM SIMULATED SINGLE ENGINE FAILURE

10. Recoveries from simulated single engine failure were performed at 80 KIAS, from a stable descent at 110% N_R with one EPCL at FLY and the EPCL of the engine to be tested at IDLE. The recovery was accomplished by moving the EPCL from IDLE to FLY. EPCL movement rates of three seconds and one second were evaluated. The data recording system was turned on prior to EPCL movement from IDLE to FLY and remained on until engine parameters stabilized.

COLLECTIVE PULSES DURING LEVEL TURNS

11. Engine/drive train stability was evaluated in left and right level turns by establishing a bank angle of 30° and setting power required to maintain constant altitude in a turn. Main rotor rpm settings from 95% to 100%, in 1% increments, were evaluated. At each rpm setting, the engine/drive train was excited by a collective pulse input. The collective pulse was accomplished by rapidly increasing the collective approximately 5% from trim, holding for one-half second, and then rapidly decreasing to the trim position. The data recording system was turned on after bank angle, power for level flight, and desired N_R was established, and remained on until engine parameters had stabilized following the collective pulse input.

COLLECTIVE FIXED TURNS

12. Left and right, descending, collective fixed turns were performed in stable flight at 120 KIAS. Load factors of +1.5, +2.0, and +2.5 were evaluated. The aircraft was stabilized at 120 KIAS at the target test altitude and collective trim position noted. The test altitude $\pm$1000 ft defined the test altitude band. The collective was fixed at the trim setting and bank angle was increased until the desired load factor was achieved. The data recording system was turned on after flight parameters had stabilized at the desired load factor and remained on for a minimum of twenty seconds.

COLLECTIVE RESPONSE

13. Collective response testing was performed with N_R set at 95% and at the maximum level flight airspeed attainable using IRP. A collective pulse input was used to excite the engine/drive train. The collective pulse was accomplished by rapidly increasing the collective approximately 5% from trim, holding for one-half second, and then rapidly decreasing to the trim position. The data recording system was turned on prior to the collective input and remained on until engine parameters had stabilized following the collective pulse input.

APPENDIX E. TEST DATA

FIGURE	FIGURE NUMBER
APU Ground Start	E-1 and E-2
APU Start in Flight	E-3 and E-4
Trim Response	E-5
Isochronous Governing Characteristics	E-6 and E-7
Jump Takeoff	E-8
Quick Stop	E-9
Button Hook	E-10
Ridgeline Crossing	E-11
Bullwhip Maneuver	E-12
Power Recovery From Autorotation	E-13
Recovery From Simulated Engine Failure	E-14
Collective Pulse During Level Turn	E-15
Collective Fixed Turn	E-16
Collective Response	E-17 and E-18
Sub-Idle Fuel Flow Modulation	E-19 and E-20

FIGURE E-1
NO. 1 ENGINE APU GROUND START
UH-60A USA S/N 88-26015

PRESSURE ALTITUDE (FEET)	OAT (DEG C)	FUEL TEMP (DEG C)	FUEL BOOST PUMP
2190	19.5	22.0	OFF

NOTES: 1. HAMILTON STANDARD HMU S/N UDAJ5284 INSTALLED ON ENGINE NO.1
2. INTERIM WOODWARD HMU S/N WY054238 INSTALLED ON ENGINE NO.2
3. NO.2 ENGINE OFF DURING START

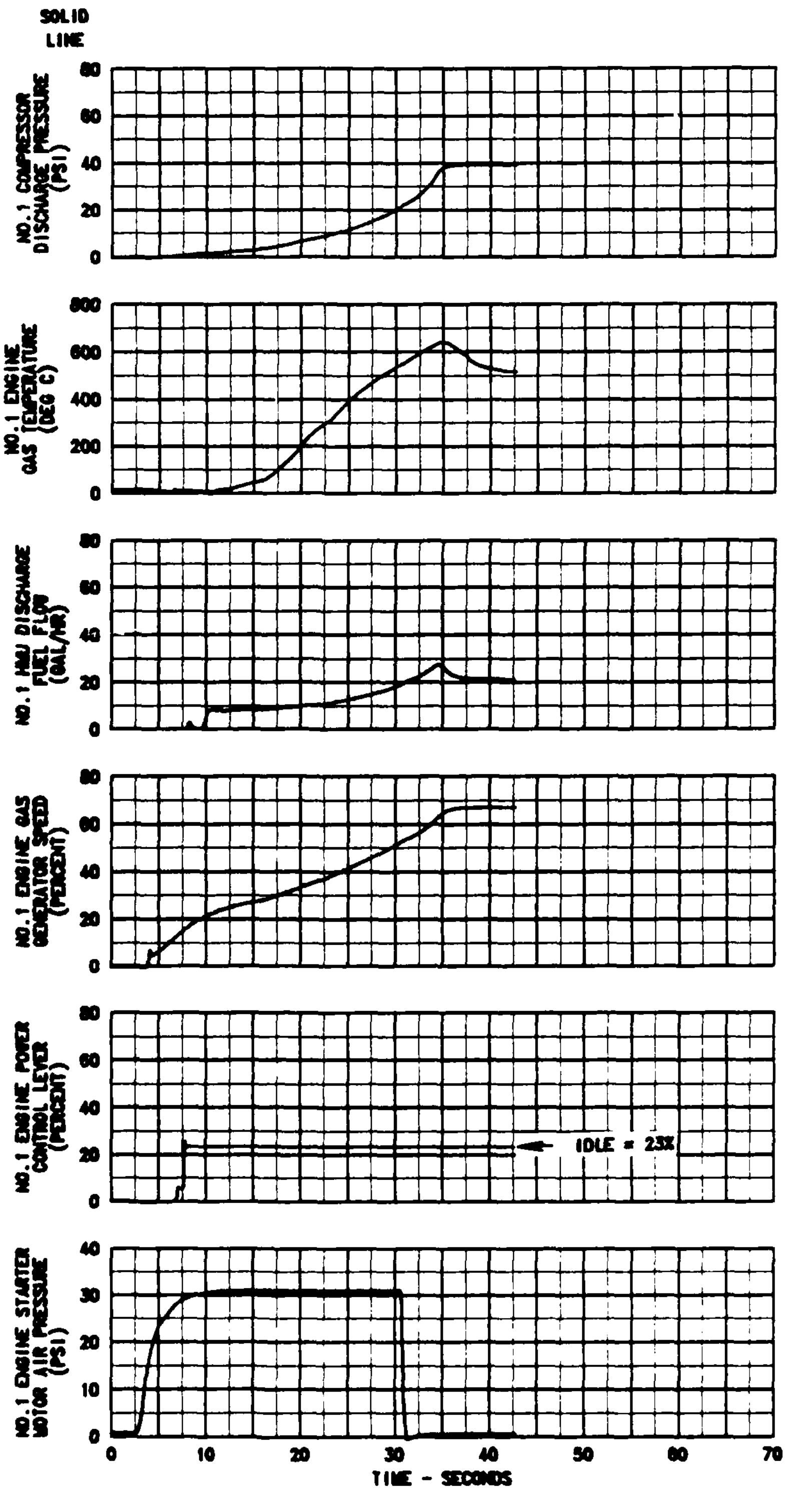


FIGURE E-2
NO.1 ENGINE APU GROUND START
UH-60A USA S/N 88-26015

PRESSURE ALTITUDE (FEET)	OAT (DEG C)	FUEL TEMP (DEG C)	FUEL BOOST PUMP
2380	31.0	26.5	ON

NOTES: 1. PRODUCTION WOODWARD HMU S/N WY054243 INSTALLED ON ENGINE NO.1
2. INTERIM WOODWARD HMU S/N WY054238 INSTALLED ON ENGINE NO.2
3. NO.2 ENGINE OFF DURING START

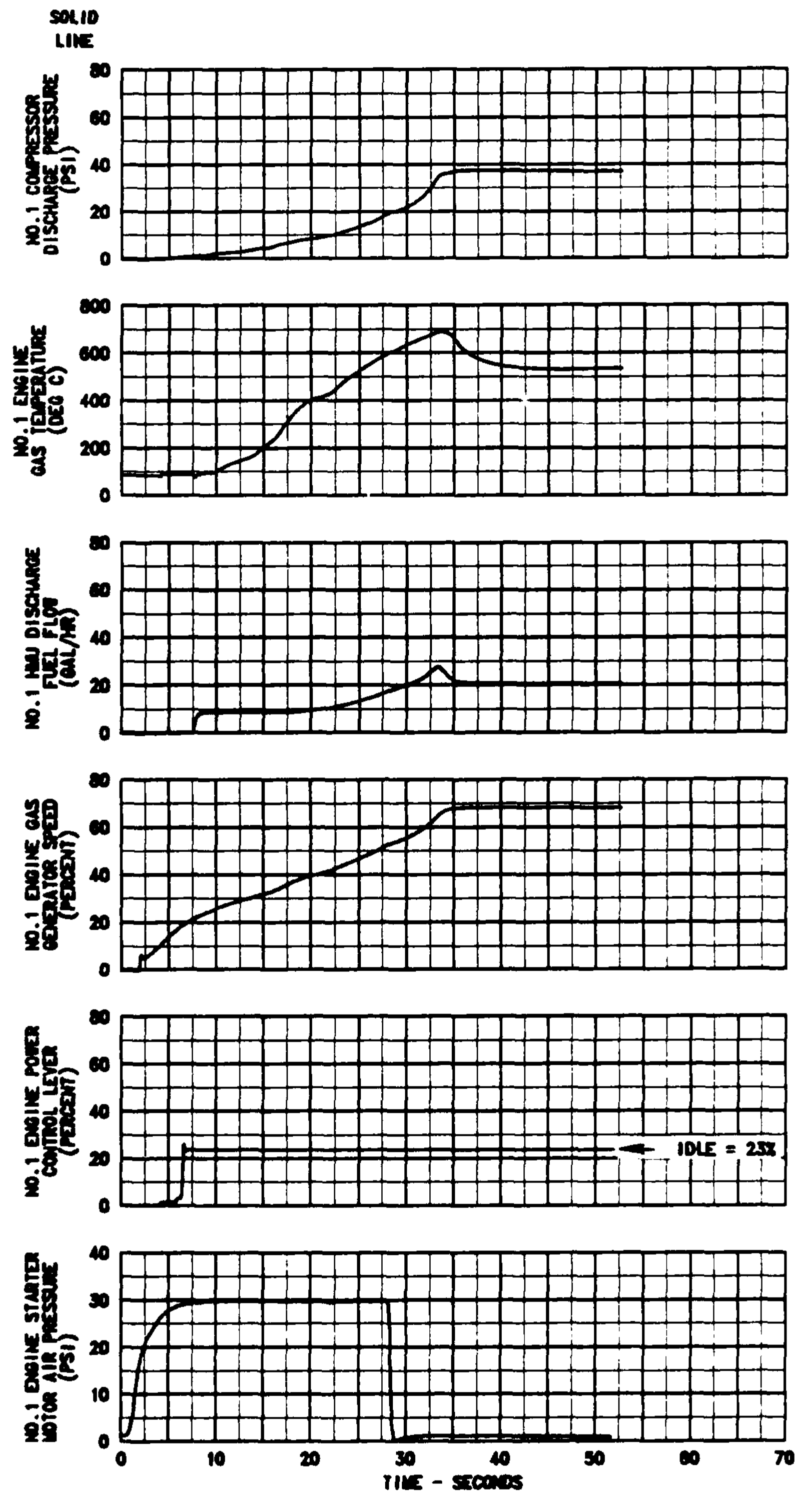


FIGURE E-3
NO.1 ENGINE APU START IN FLIGHT
UH-60A USA S/N 88-26015

AVG GROSS WEIGHT (LB)	AVG CG LOCATION LONG (FS)	AVG CG LOCATION LAT (BL)	PRESSURE ALTITUDE (FEET)	AVG OAT (DEG C)	ROTOR SPEED (RPM)	TRIM INDICATED AIRSPEED (KNOTS)	FUEL TEMP (DEG C)	FUEL BOOST PUMP
13650	358.1(MID)	0.4LT	19350	-12.5	257	54	24.5	OFF

NOTES: 1. HAMILTON STANDARD HMU S/N UDAJ5284 INSTALLED ON ENGINE NO.1
2. INTERIM WOODWARD HMU S/N WYG54238 INSTALLED ON ENGINE NO.2

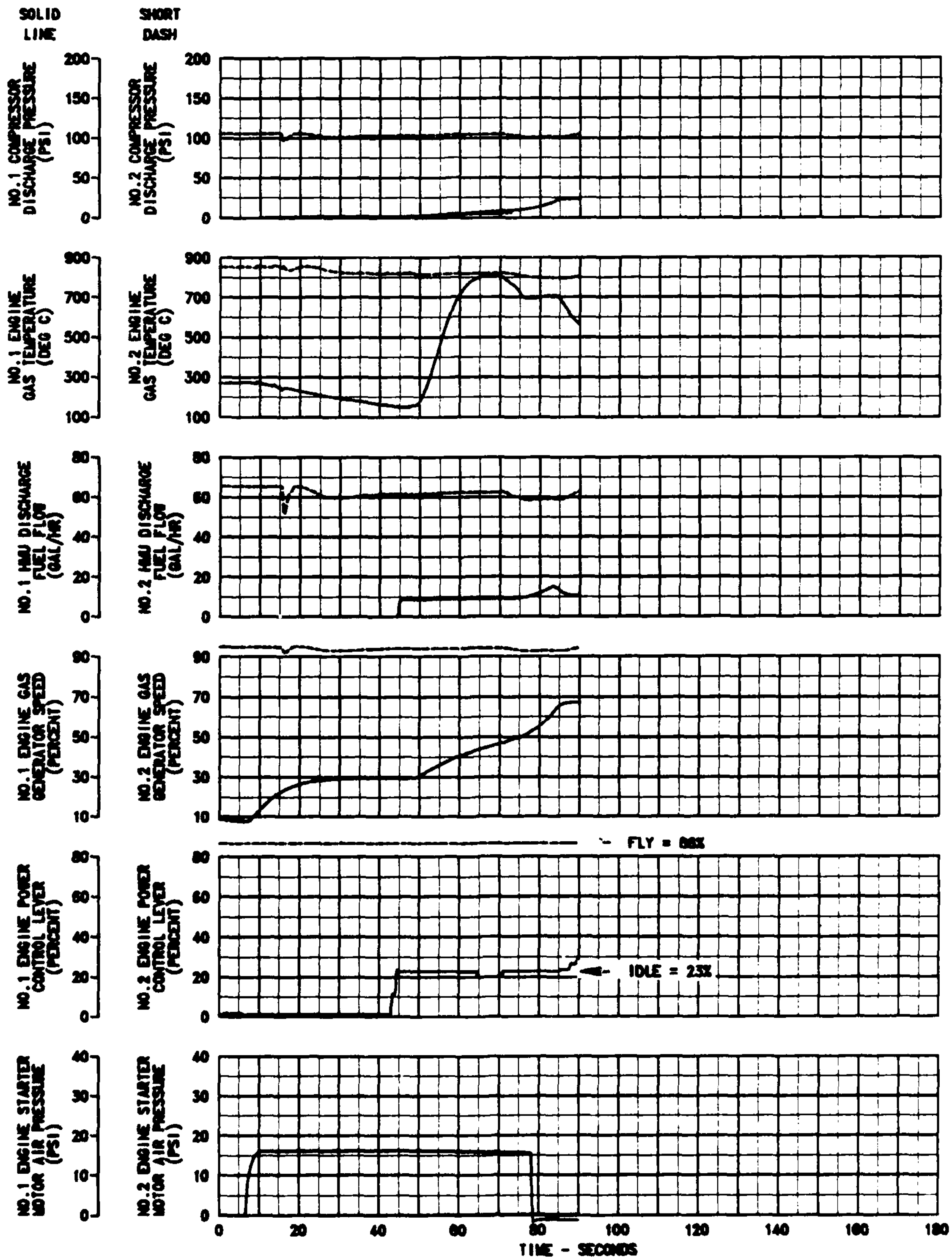


FIGURE E-4

NO.1 ENGINE APU START IN FLIGHT

UH-60A USA S/N 88-26015

AVG GROSS WEIGHT (LB)	AVG CG LOCATION LONG (FS)	AVG CG LOCATION LAT (BL)	PRESSURE ALTITUDE (FEET)	AVG OAT (DEG C)	ROTOR SPEED (RPM)	TRIM INDICATED AIRSPEED (KNOTS)	FUEL TEMP (DEG C)	FUEL BOOST PUMP
14460	355.8(MID)	0.5LT	19180	-12.5	258	41	28.0	ON

NOTES: 1. PRODUCTION WOODWARD HMU S/N WYG54243 INSTALLED ON ENGINE NO.1
2. INTERIM WOODWARD HMU S/N WYG54238 INSTALLED ON ENGINE NO.2

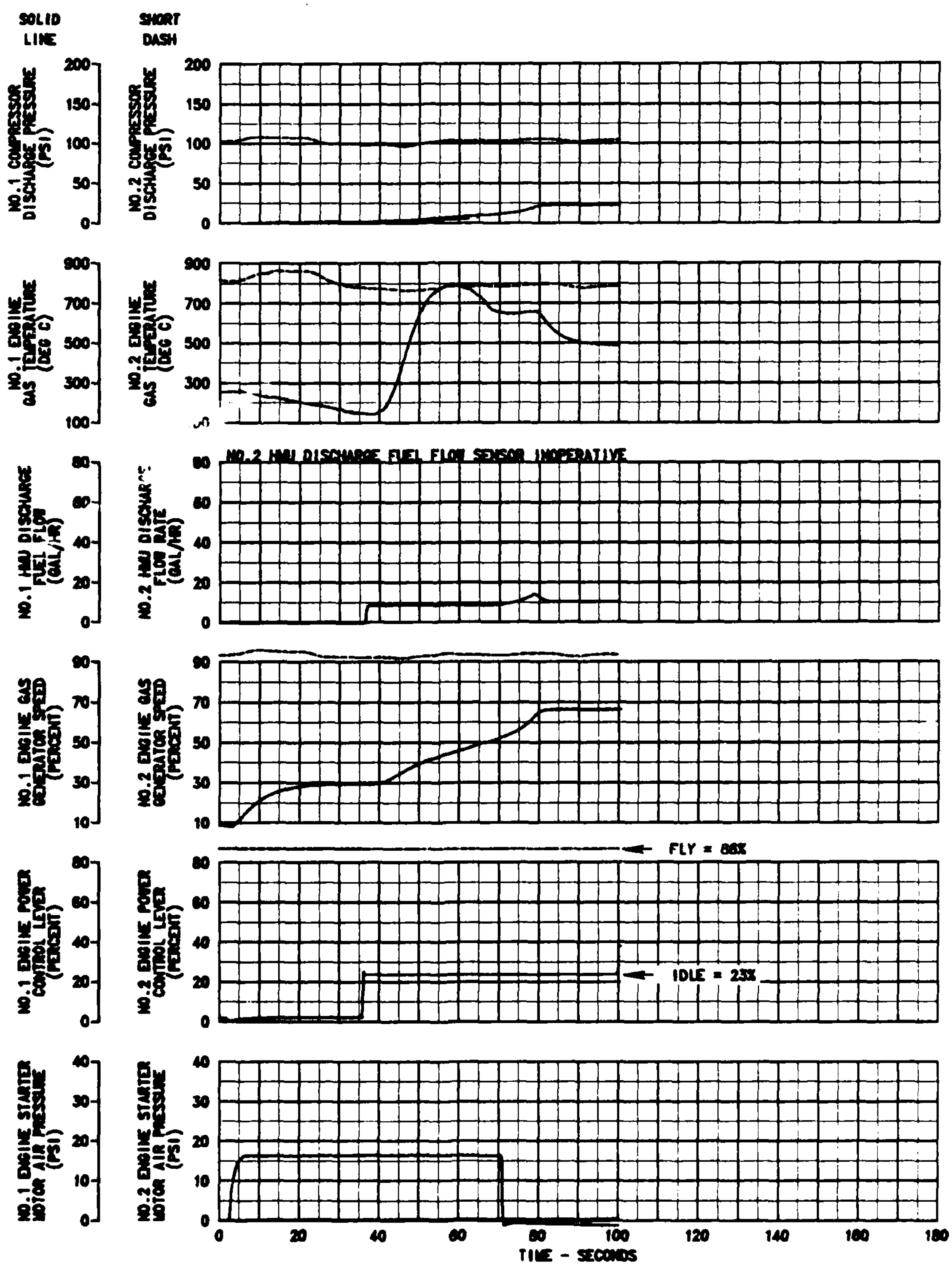


FIGURE E-5
NO.2 ENGINE TRIM RESPONSE
UH-60A USA S/N 88-26015

PRESSURE ALTITUDE (FEET)	OAT (DEG C)	INDICATED AIRSPEED (KNOTS)
2310	17.0	0

NOTES: 1. INTERIM WOODWARD HMU S/N WYG54250 INSTALLED ON ENGINE NO.1
2. INTERIM WOODWARD HMU S/N WYG54238 INSTALLED ON ENGINE NO.2

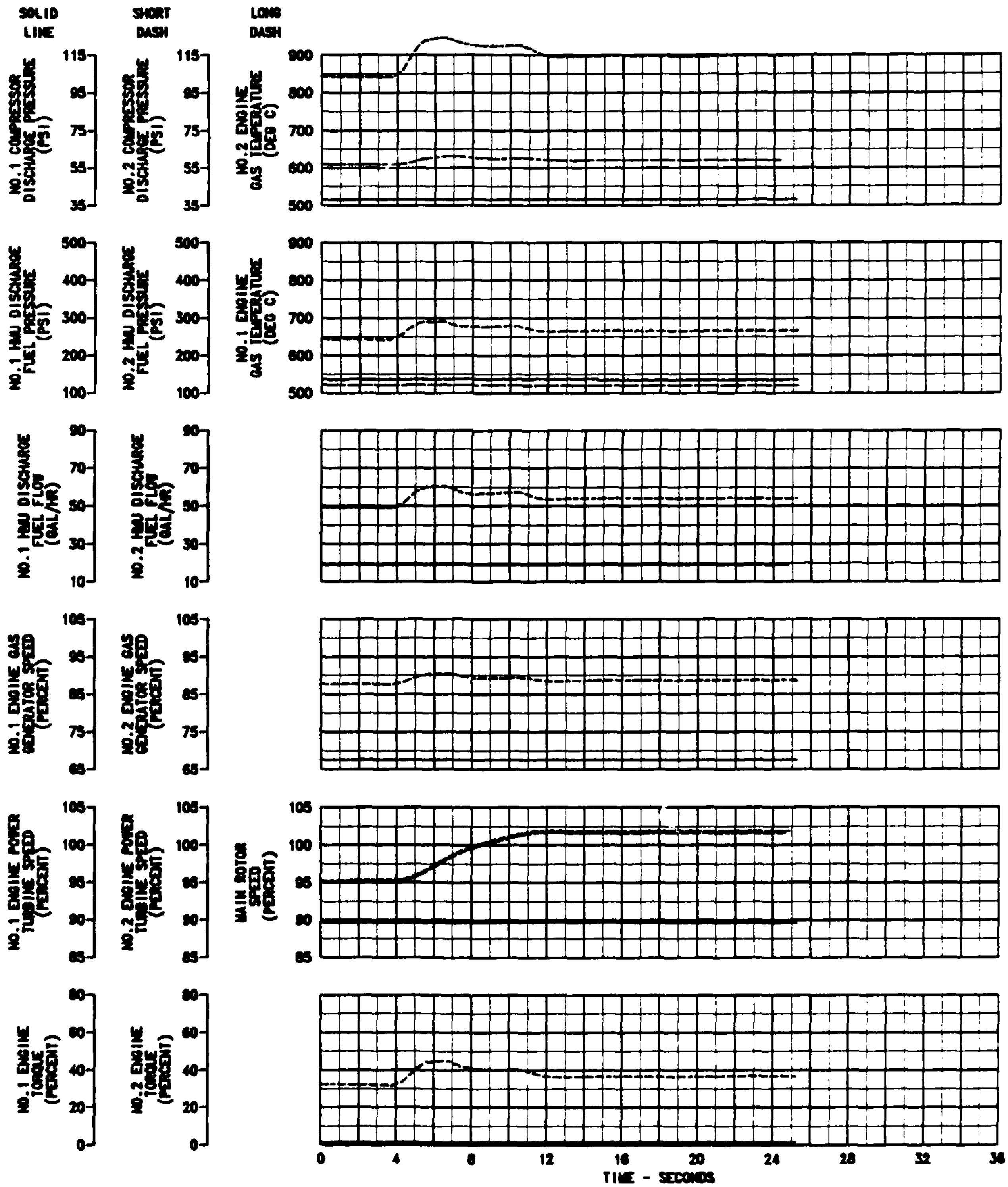


FIGURE E-6
INTERIM WOODWARD HMU ISOCHRONOUS GOVERNING CHARACTERISTICS
UH-60A USA S/N 88-26015

PRESSURE ALTITUDE (FEET)	OAT (DEG C)	INDICATED AIRSPEED (KNOTS)
2340	36.0	0

NOTES: 1. PRODUCTION WOODWARD HMU S/N WYG54243 INSTALLED ON ENGINE NO.1
2. INTERIM WOODWARD HMU S/N WYG54238 INSTALLED ON ENGINE NO.2

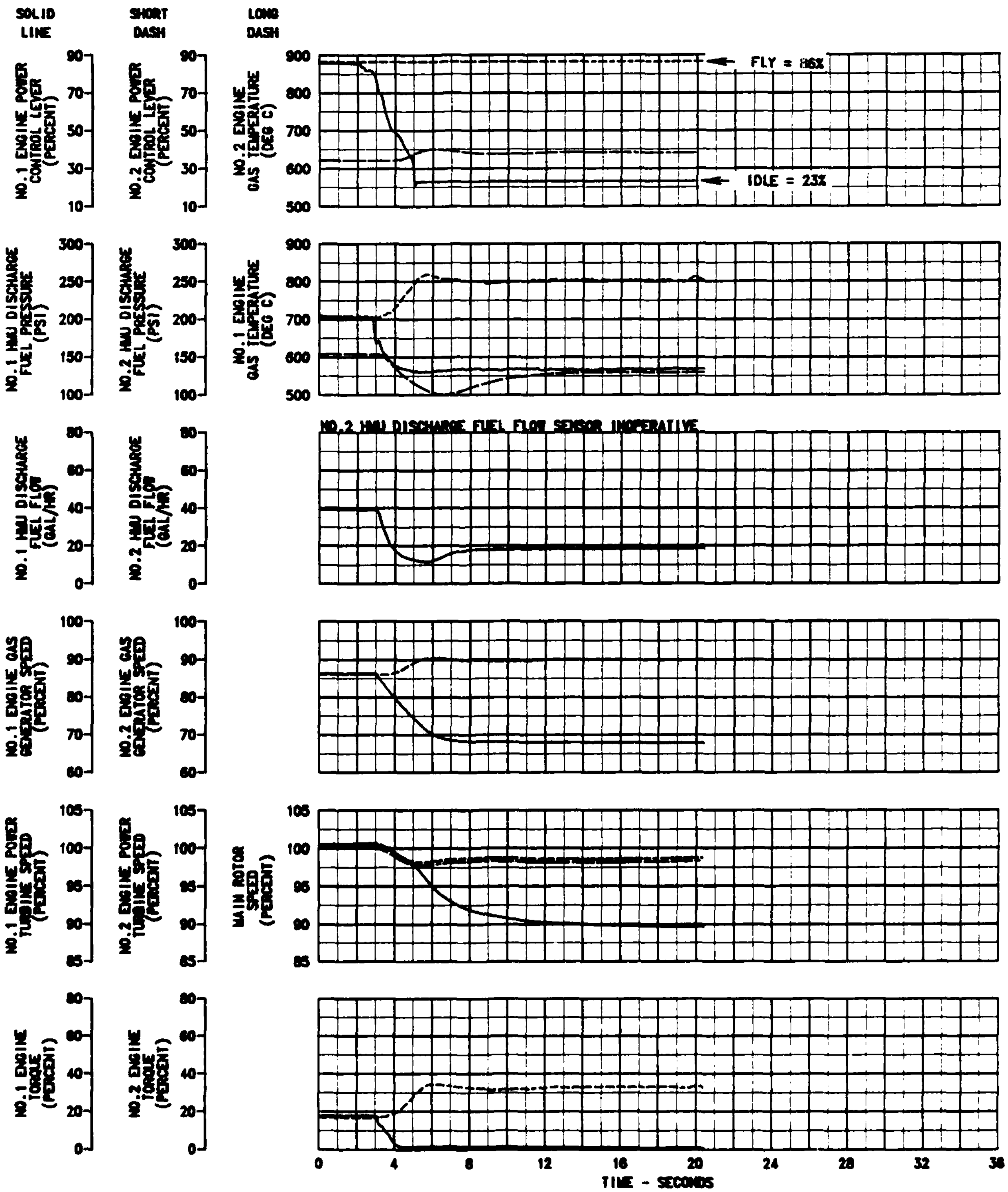


FIGURE E-7
PRODUCTION WOODWARD HMU ISOCHRONOUS GOVERNING CHARACTERISTICS
UH-60A USA S/N 88-26015

PRESSURE ALTITUDE (FEET)	OAT (DEG C)	INDICATED AIRSPEED (KNOTS)
2340	36.0	0

NOTES: 1. PRODUCTION WOODWARD HMU S/N WYG54243 INSTALLED ON ENGINE NO.1
2. INTERIM WOODWARD HMU S/N WYG54238 INSTALLED ON ENGINE NO.2

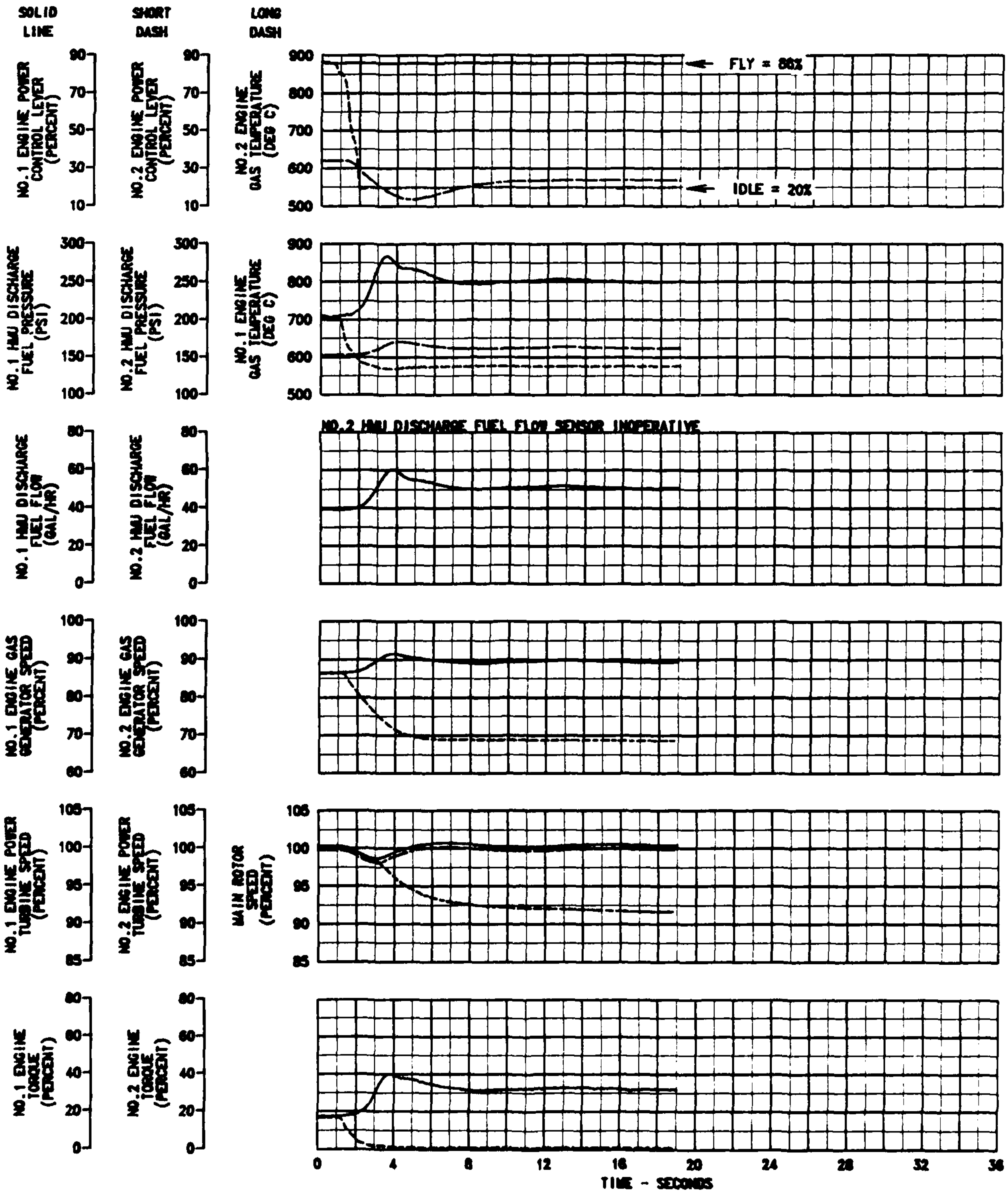


FIGURE E-8
JUMP TAKEOFF
UH-60A USA S/N 88-26015

AVG GROSS WEIGHT (LB)	AVG CG LOCATION LONG (FS)	AVG CG LOCATION LAT (BL)	PRESSURE ALTITUDE (FEET)	AVG OAT (DEG C)	ROTOR SPEED (RPM)	TRIM INDICATED AIRSPEED (KNOTS)
14750	358.4(MID)	0.7LT	2220	28.5	257	0

NOTES: 1. HAMILTON STANDARD HMU S/N UDAJ5284 INSTALLED ON ENGINE NO.1
2. INTERIM WOODWARD HMU S/N WYG54238 INSTALLED ON ENGINE NO.2

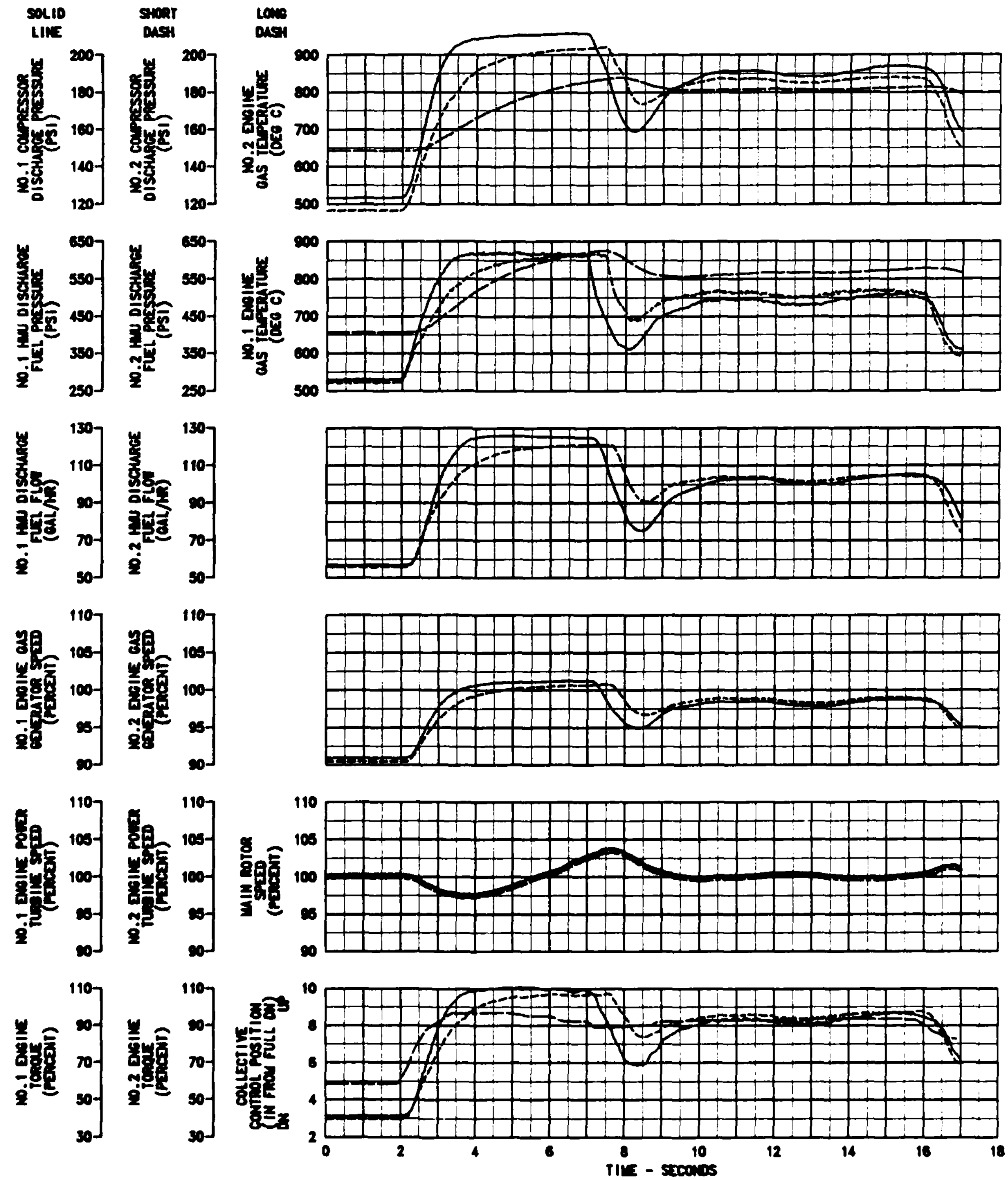


FIGURE E-9
QUICK STOP
UH-60A USA S/N 88-26015

AVG GROSS WEIGHT (LB)	AVG CG LOCATION LONG (FS)	AVG CG LOCATION LAT (BL)	PRESSURE ALTITUDE (FEET)	AVG OAT (DEG C)	ROTOR SPEED (RPM)	TRIM INDICATED AIRSPEED (KNOTS)
14080	354.3(MID)	0.6LT	2300	21.0	258	129

NOTES: 1. HAMILTON STANDARD HMU S/N UDAJ5284 INSTALLED ON ENGINE NO.1
2. INTERIM WOODWARD HMU S/N WY054238 INSTALLED ON ENGINE NO.2

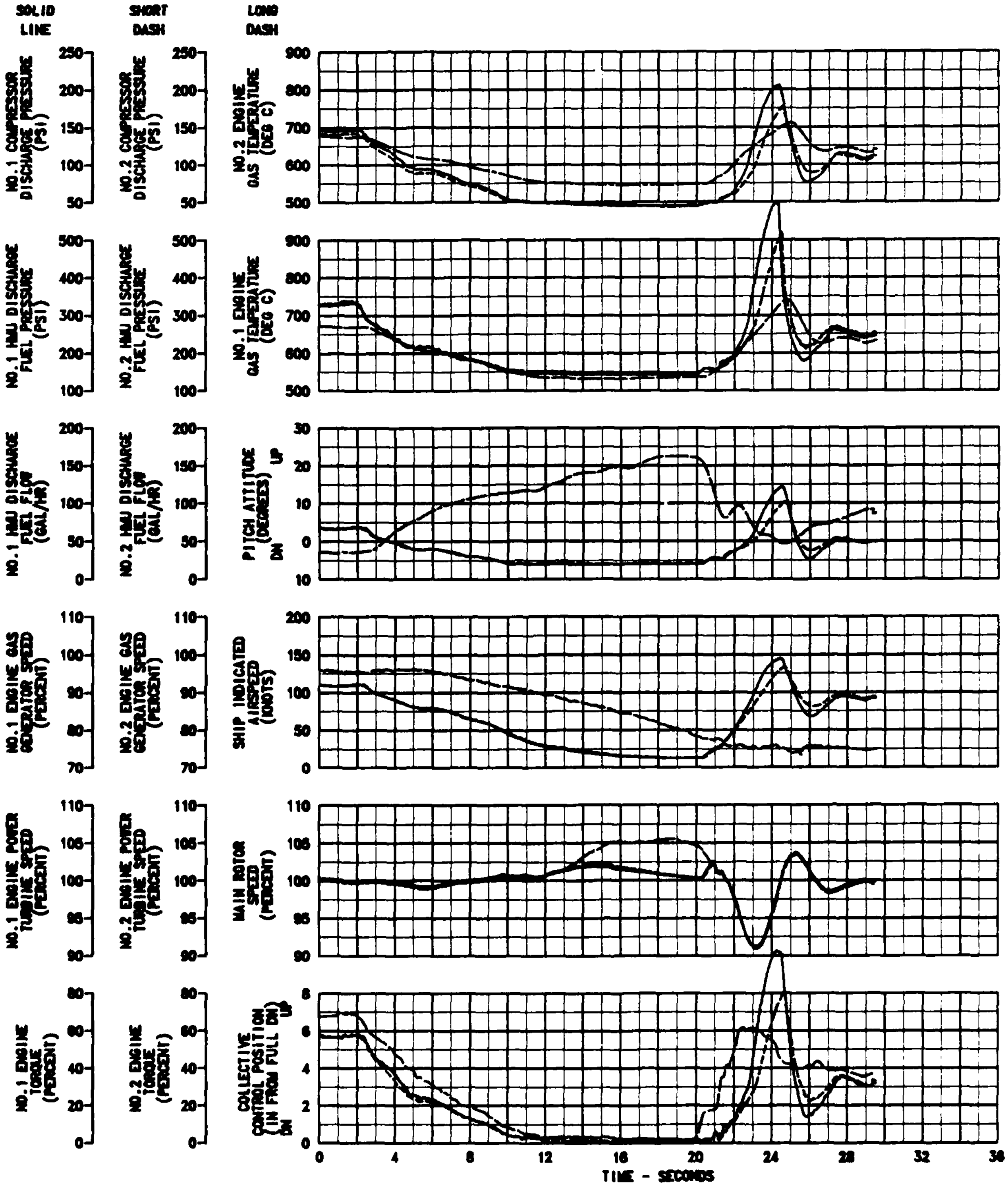


FIGURE E-10
BUTTON HOOK
UH-60A USA S/N 88-26015

AVG GROSS WEIGHT (LB)	AVG CG LOCATION LONG (FS)	LAT (BL)	PRESSURE ALTITUDE (FEET)	AVG OAT (DEG C)	ROTOR SPEED (RPM)	TRIM INDICATED AIRSPEED (KNOTS)
14580	357.8(MID)	0.7LT	2680	27.0	257	127

NOTES: 1. INTERIM WOODWARD HMU S/N WYG54250 INSTALLED ON ENGINE NO.1
2. INTERIM WOODWARD HMU S/N WYG54238 INSTALLED ON ENGINE NO.2

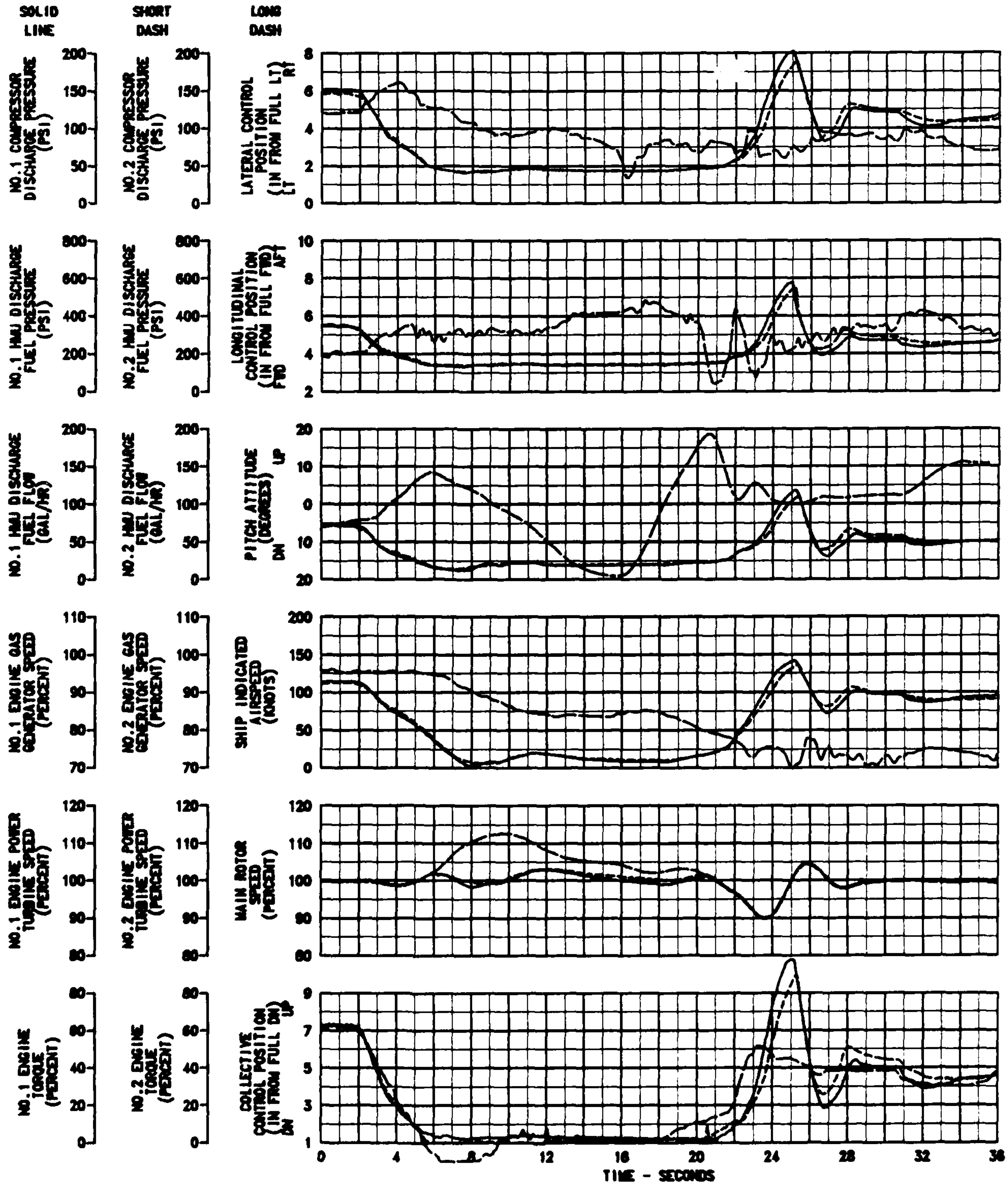


FIGURE E-11
RIDGELINE CROSSING
UH-60A USA S/N 88-26015

AVG GROSS WEIGHT (LB)	AVG CG LOCATION LONG (FS)	AVG CG LOCATION LAT (BL)	PRESSURE ALTITUDE (FEET)	AVG OAT (DEG C)	ROTOR SPEED (RPM)	TRIM INDICATED AIRSPEED (KNOTS)
13650	353.4(MID)	0.8LT	3060	17.0	258	133

NOTES: 1. INTERIM WOODWARD HMU S/N WYG54250 INSTALLED ON ENGINE NO.1
2. INTERIM WOODWARD HMU S/N WYG54238 INSTALLED ON ENGINE NO.2

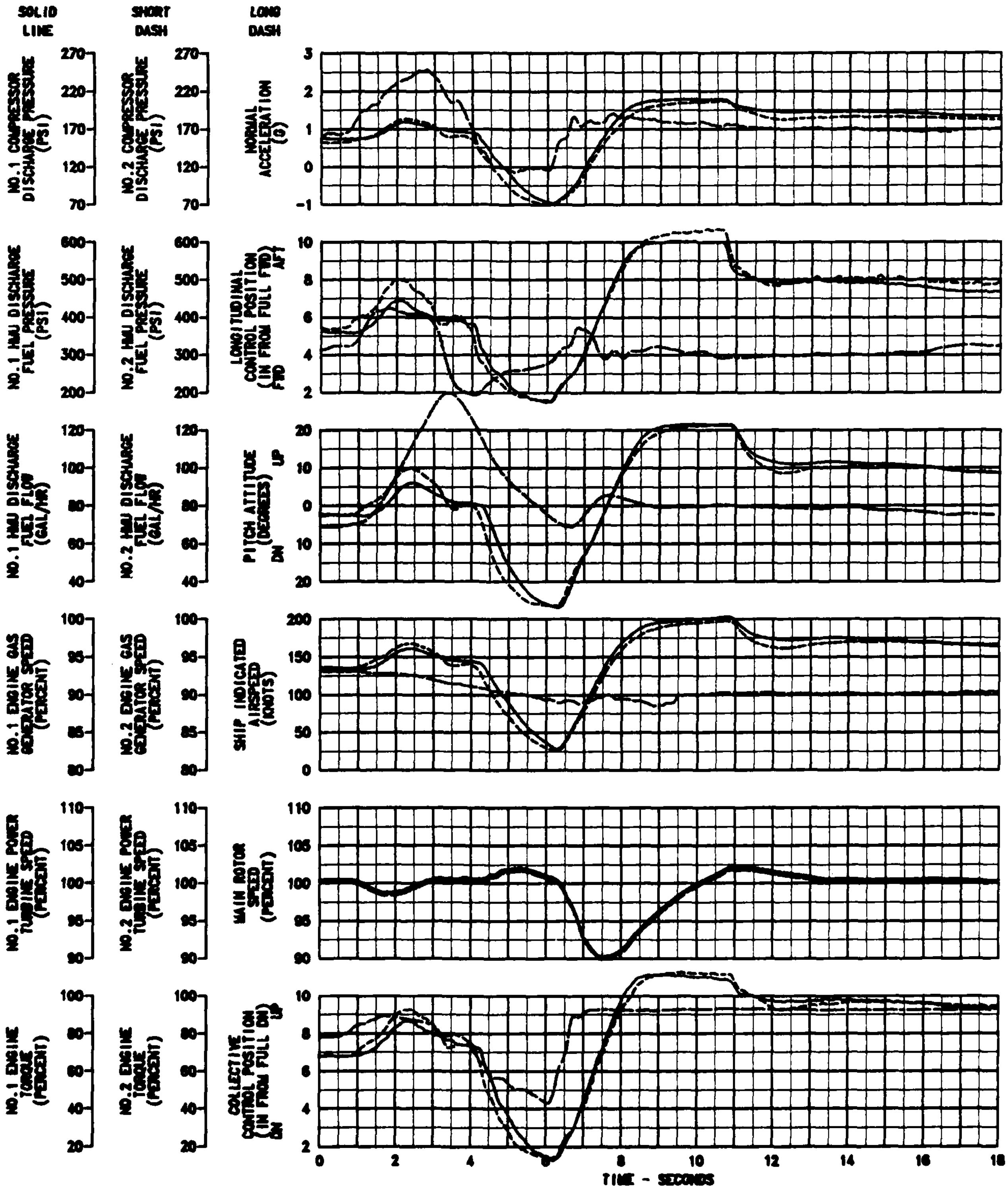


FIGURE E-12
BULLWHIP MANEUVER
UH-60A USA S/N 88-26015

AVG GROSS WEIGHT (LB)	AVG CG LOCATION LONG (FS)	AVG CG LOCATION LAT (BL)	PRESSURE ALTITUDE (FEET)	AVG OAT (DEG C)	ROTOR SPEED (RPM)	TRIM INDICATED AIRSPEED (KNOTS)
13820	352.7(MID)	0.4LT	10450	4.5	257	73

NOTES: 1. PRODUCTION WOODWARD HMU S/N WYG54243 INSTALLED ON ENGINE NO.1
2. INTERIM WOODWARD HMU S/N WYG54238 INSTALLED ON ENGINE NO.2

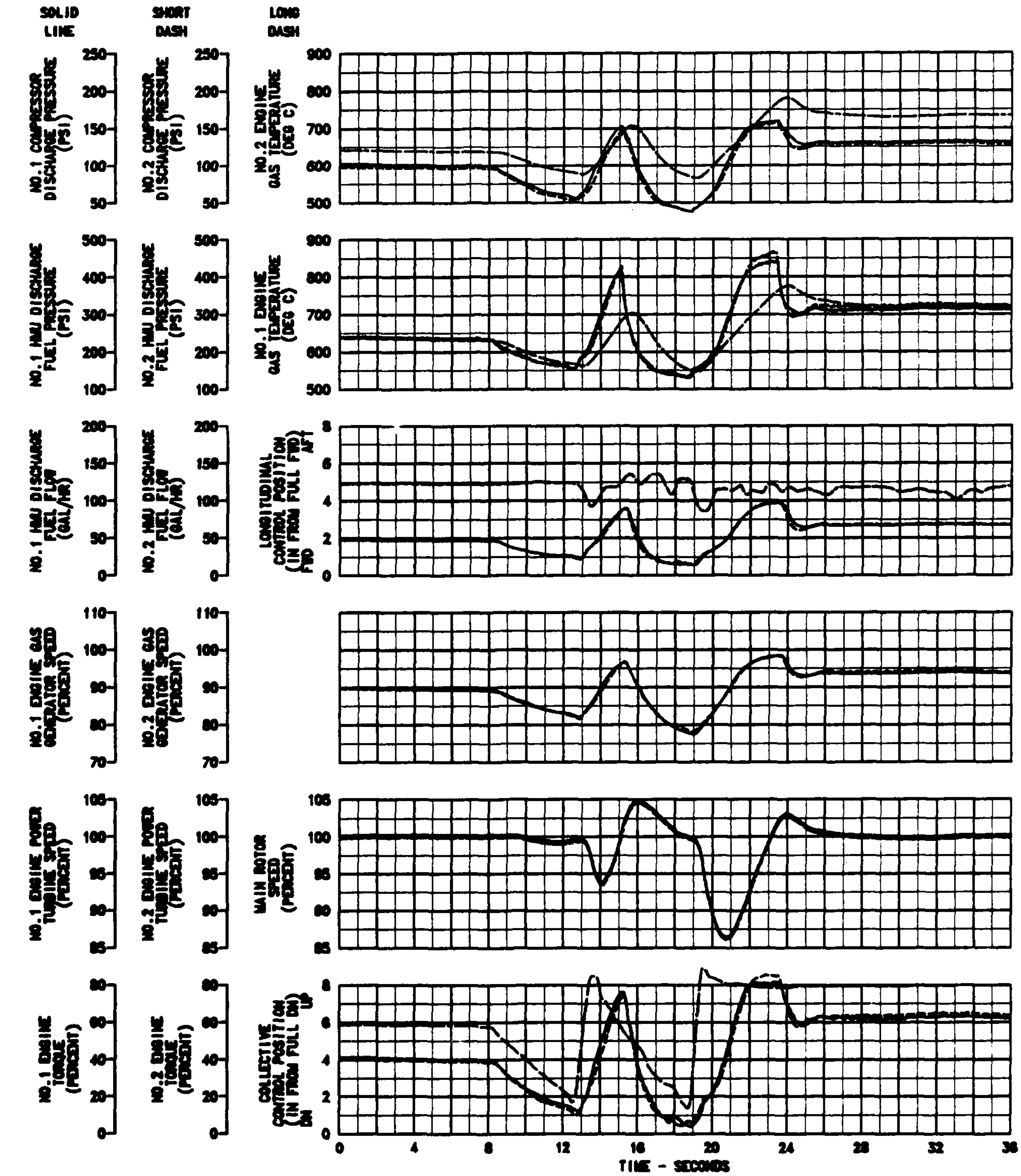


FIGURE E-13
POWER RECOVERY FROM AUTOROTATION
UH-60A USA S/N 88-26015

AVG GROSS WEIGHT (LB)	AVG CG LOCATION LONG (FS)	AVG CG LOCATION LAT (BL)	AVG OAT (DEG C)	FUEL TEMP (DEG C)	FUEL BOOST PUMP
14650	356.7(MID)	0.6LT	11.0	27	OFF

NOTES 1. PRODUCTION WOODWARD HMU S/N WYG54243 INSTALLED ON ENGINE NO.1
2. INTERIM WOODWARD HMU S/N WYG54238 INSTALLED ON ENGINE NO.2

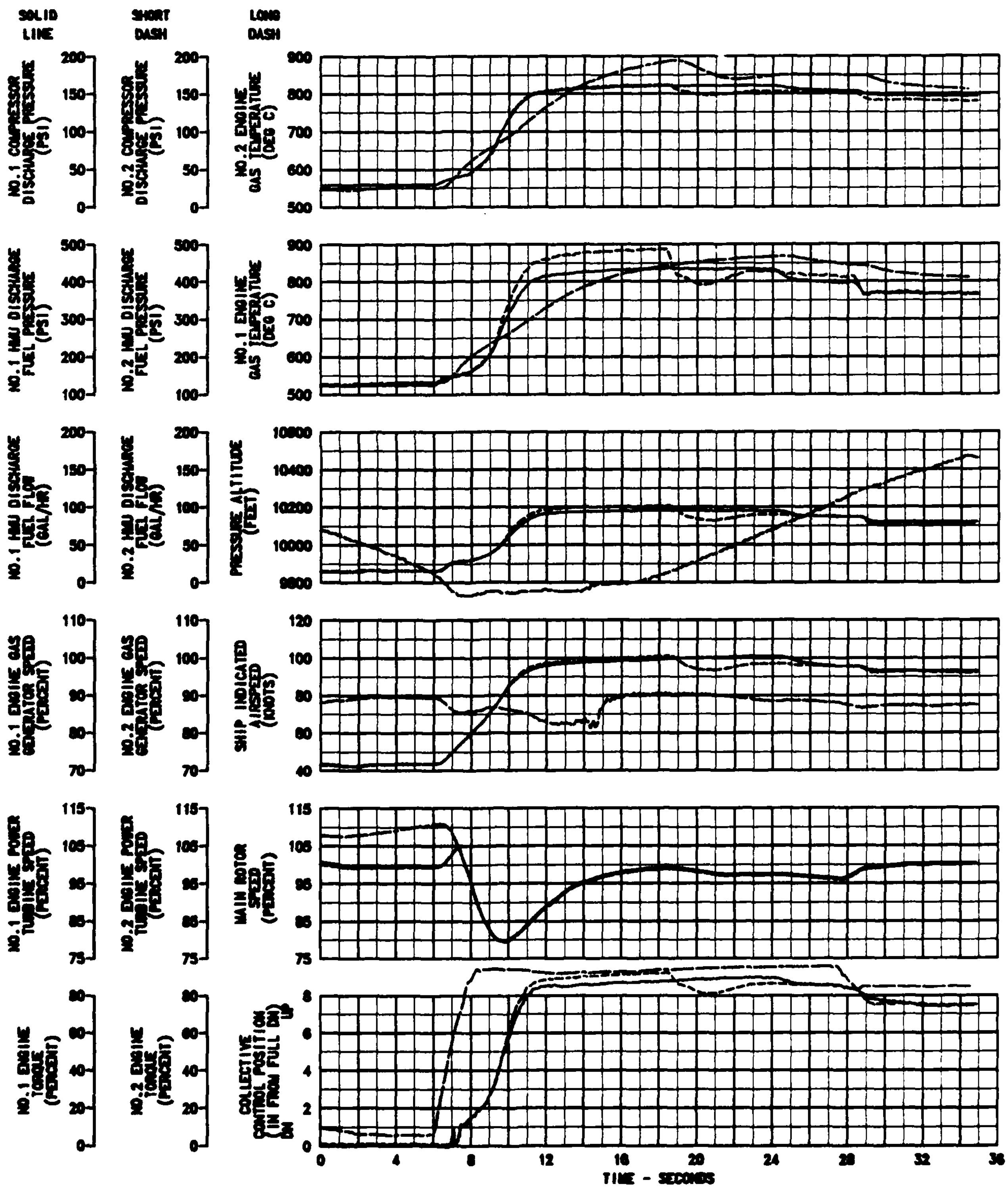


FIGURE E-14
RECOVERY FROM SIMULATED NO.2 ENGINE FAILURE
UH-60A USA S/N 88-26015

AVG GROSS WEIGHT (LB)	AVG CG LOCATION LONG (FS)	AVG CG LOCATION LAT (BL)	AVG OAT (DEG C)	FUEL TEMP (DEG C)	FUEL BOOST PUMP
14270	360.8(MID)	0.4LT	-5.5	24.0	OFF

NOTES: 1. HAMILTON STANDARD HMU S/N UDAJ5284 INSTALLED ON ENGINE NO.1
2. INTERIM WOODWARD HMU S/N WYG54238 INSTALLED ON ENGINE NO.2

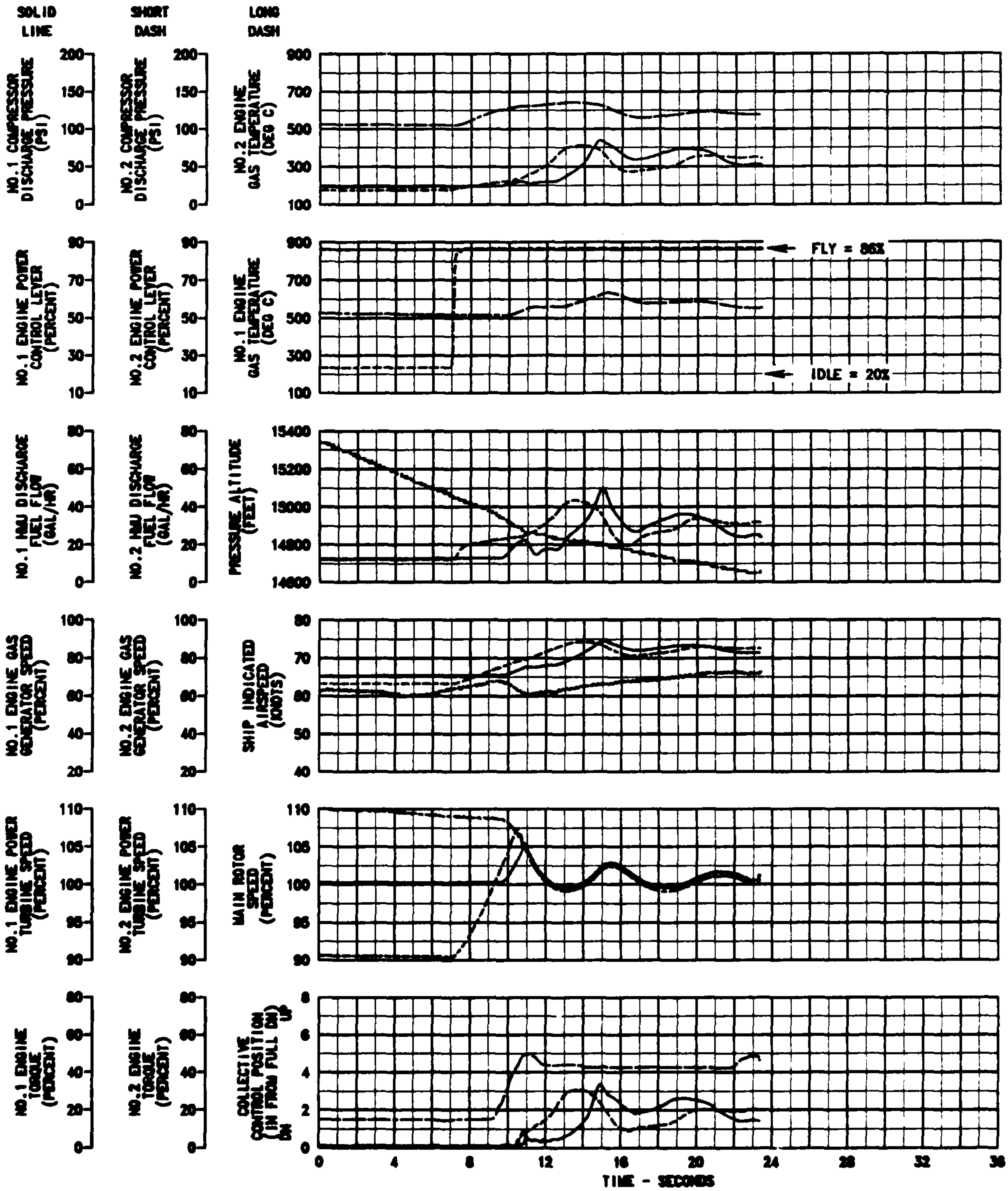


FIGURE E-15
COLLECTIVE PULSE DURING LEVEL TURN
UH-60A USA S/N 88-26015

AVG GROSS WEIGHT (LB)	AVG CG LOCATION LONG (FS)	AVG CG LOCATION LAT (BL)	PRESSURE ALTITUDE (FEET)	AVG OAT (DEG C)	ROTOR SPEED (RPM)	TRIM INDICATED AIRSPEED (KNOTS)
13790	352.9(MID)	0.4LT	15120	-3.0	258	93

NOTES: 1. HAMILTON STANDARD HMU S/N UDAJ5284 INSTALLED ON ENGINE NO.1
2. INTERIM WOODWARD HMU S/N WYG54238 INSTALLED ON ENGINE NO.2

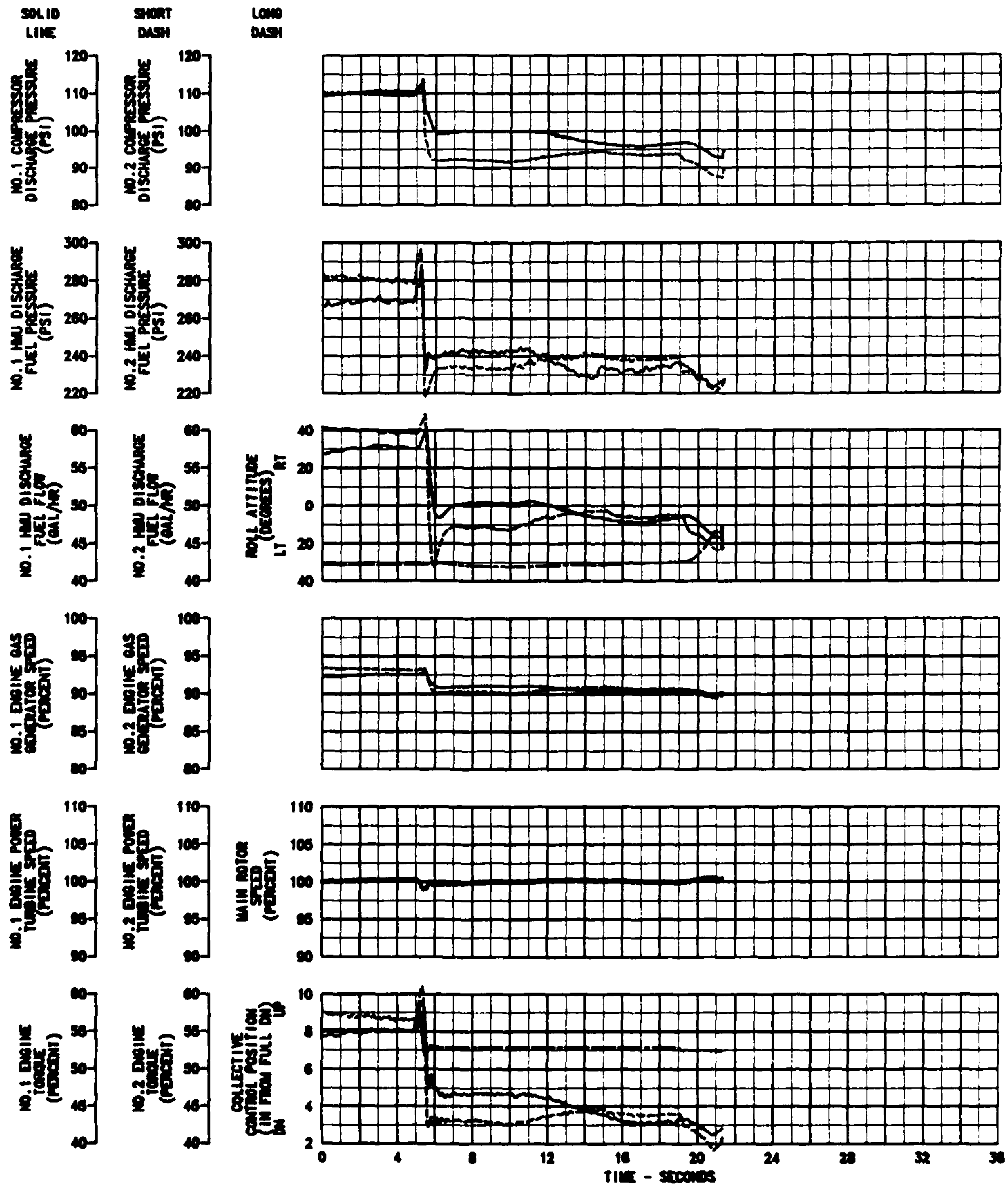


FIGURE E-16
COLLECTIVE FIXED RIGHT TURN
UH-60A USA S/N 88-26015

AVG GROSS WEIGHT (LB)	AVG CG LOCATION LONG (FS)	AVG CG LOCATION LAT (BL)	PRESSURE ALTITUDE (FEET)	AVG OAT (DEG C)	ROTOR SPEED (RPM)	TRIM INDICATED AIRSPEED (KNOTS)
14500	356.2(MID)	0.4LT	8820	10.0	258	92

NOTES: 1. HAMILTON STANDARD HMU S/N UDAJ5284 INSTALLED ON ENGINE NO.1
2. INTERIM WOODWARD HMU S/N WY054238 INSTALLED ON ENGINE NO.2

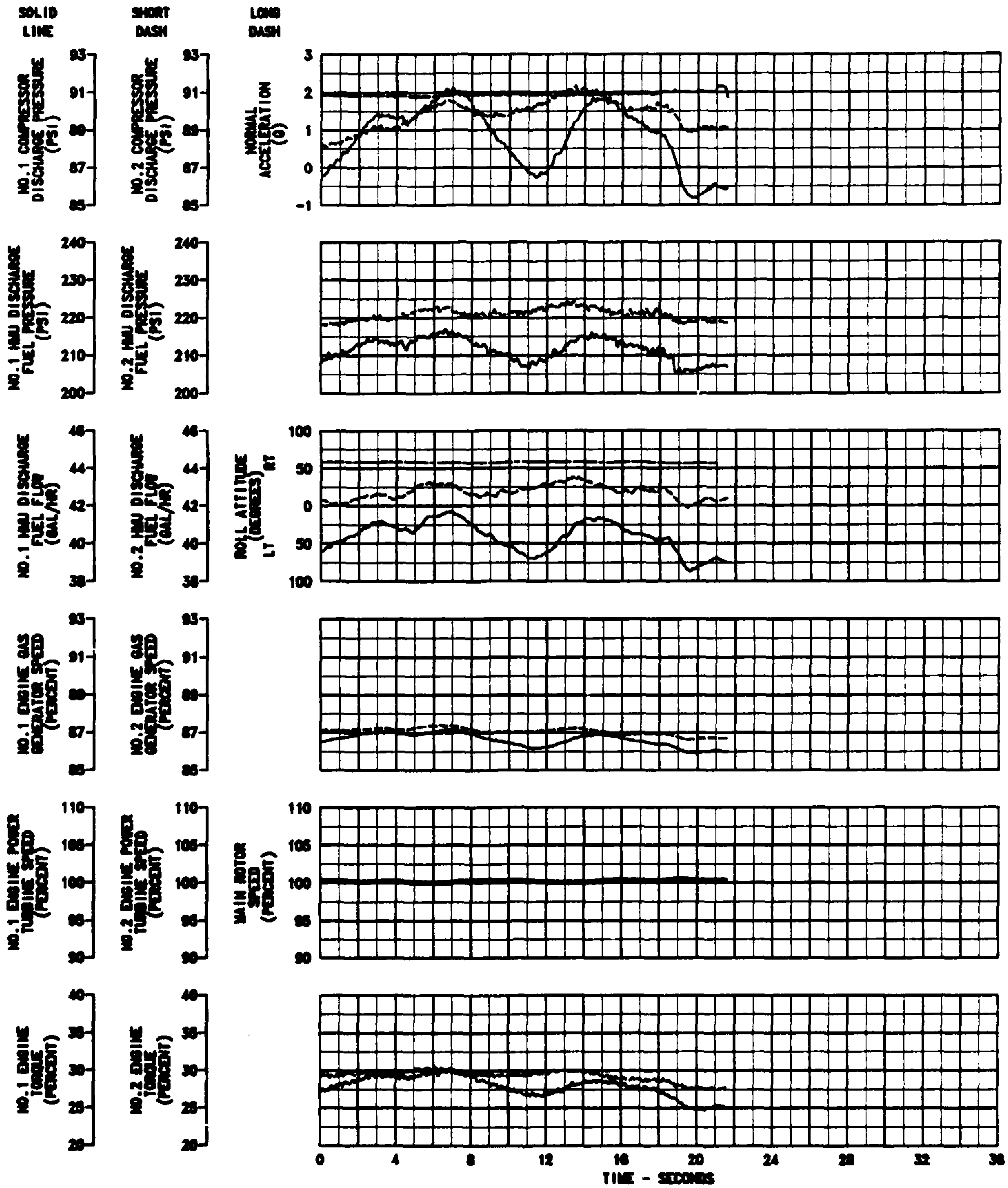


FIGURE E-17

COLLECTIVE RESPONSE

UH-60A USA S/N 88-26015

AVG GROSS WEIGHT (LB)	AVG CG LOCATION LONG (FS)	AVG CG LOCATION LAT (BL)	PRESSURE ALTITUDE (FEET)	AVG OAT (DEG C)	ROTOR SPEED (RPM)	TRIM INDICATED AIRSPEED (KNOTS)	ANTI-ICE
13750	355.9(MID)	0.4LT	14040	-3.0	243	90	ON

NOTES: 1. HAMILTON STANDARD HMU S/N UDAJ5284 INSTALLED ON ENGINE NO.1
2. INTERIM WOODWARD HMU S/N WYGS4238 INSTALLED ON ENGINE NO.2

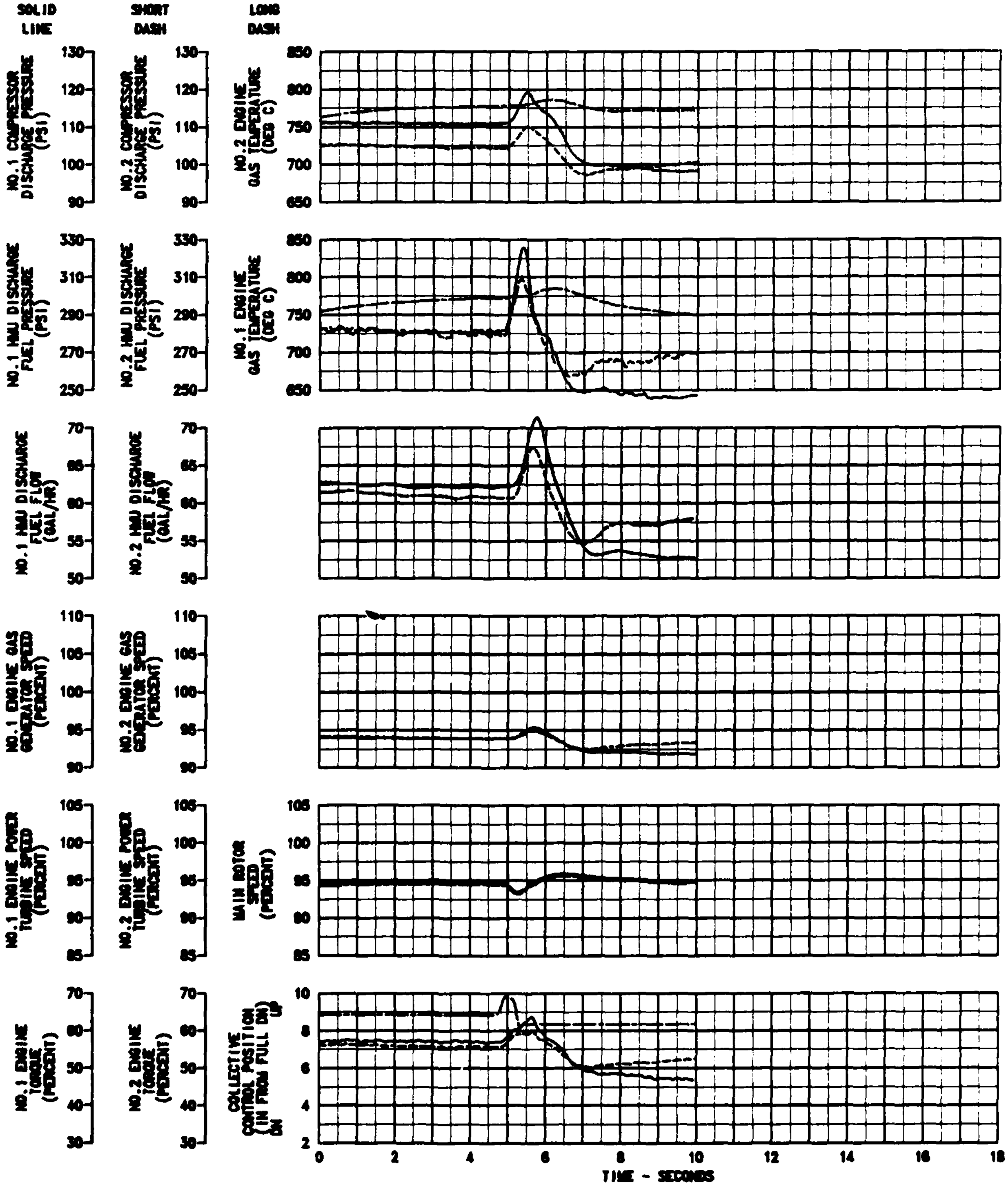


FIGURE E-18
COLLECTIVE RESPONSE
UH-60A USA S/N 88-26015

AVG GROSS WEIGHT (LB)	AVG CG LOCATION LONG (FS)	AVG CG LOCATION LAT (BL)	PRESSURE ALTITUDE (FEET)	AVG OAT (DEG C)	ROTOR SPEED (RPM)	TRIM INDICATED AIRSPEED (KNOTS)	ANTI-ICE
13750	355.9(MID)	0.4LT	14860	-3.0	246	99	OFF

NOTES: 1. HAMILTON STANDARD HMU S/N UDAJ5284 INSTALLED ON ENGINE NO.1
2. INTERIM WOODWARD HMU S/N WYG54238 INSTALLED ON ENGINE NO.2

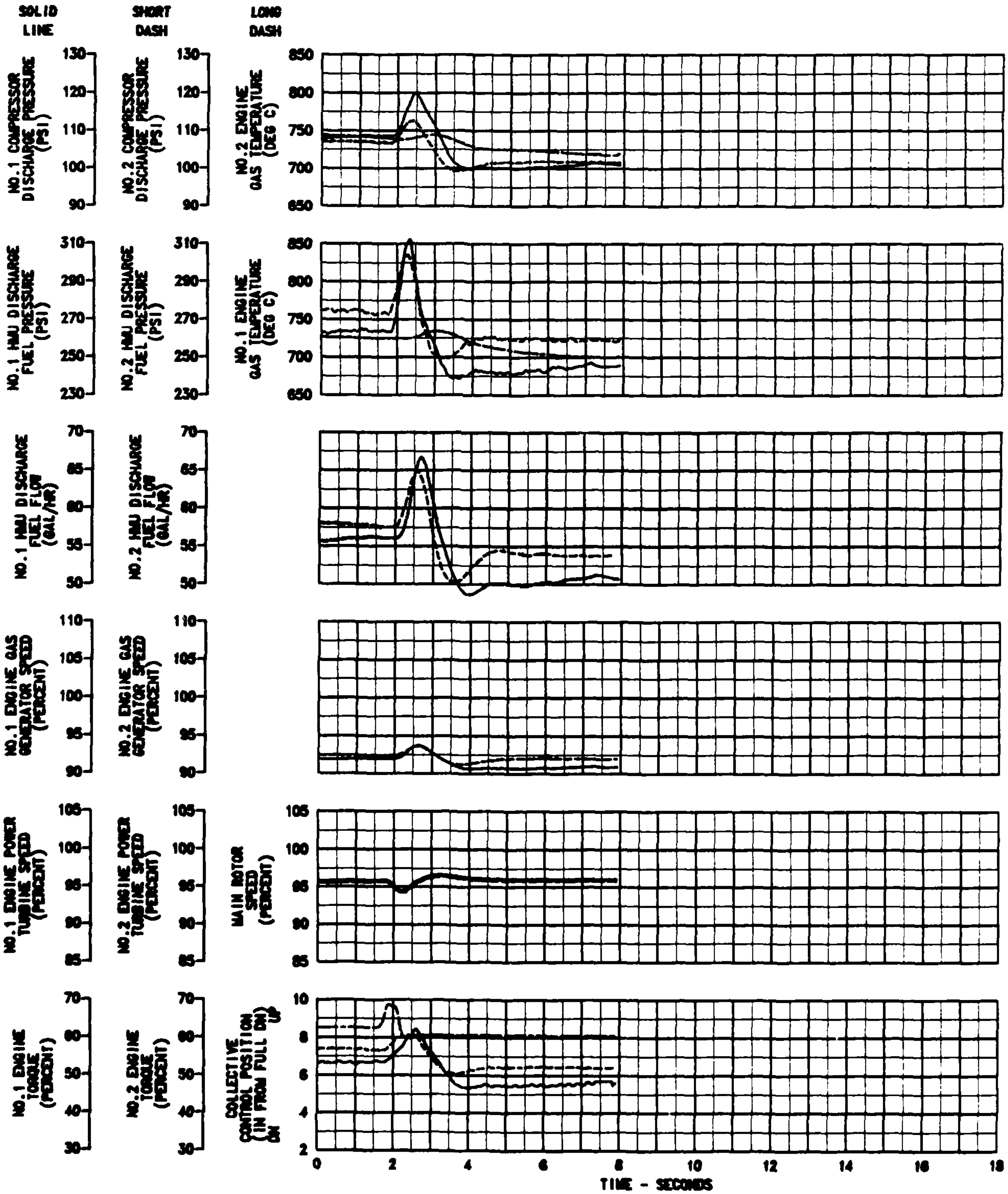


FIGURE E-19
SUB-IDLE FUEL FLOW MODULATION
UH-60A USA S/N 88-26015

PRESSURE ALTITUDE (FEET)	OAT (DEG C)	INDICATED AIRSPEED (KNOTS)
2200	23.5	0

NOTES: 1. HAMILTON STANDARD HMU S/N UDAJ5284 INSTALLED ON ENGINE NO.1
2. INTERIM WOODWARD HMU S/N WYG54238 INSTALLED ON ENGINE NO.2

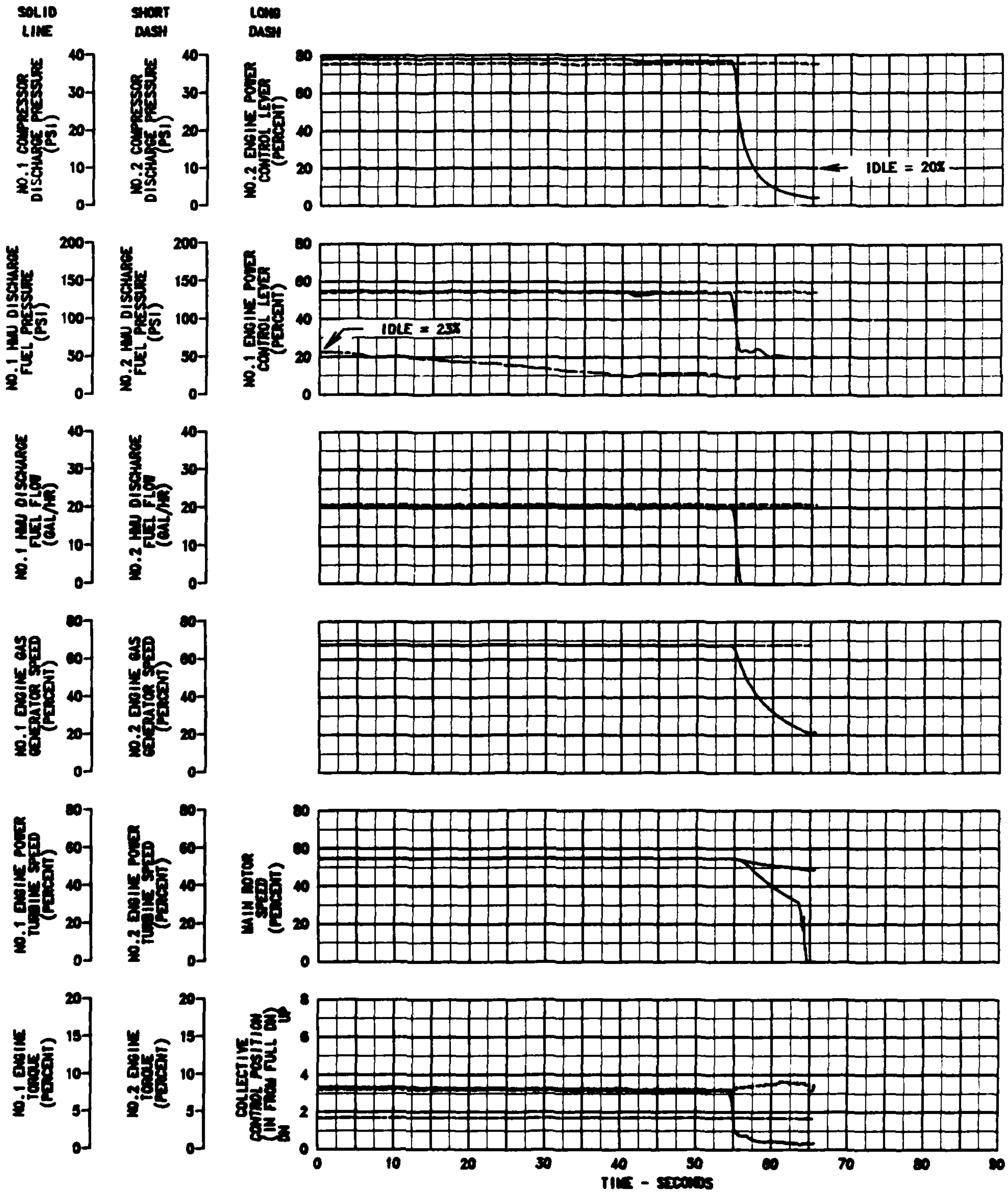
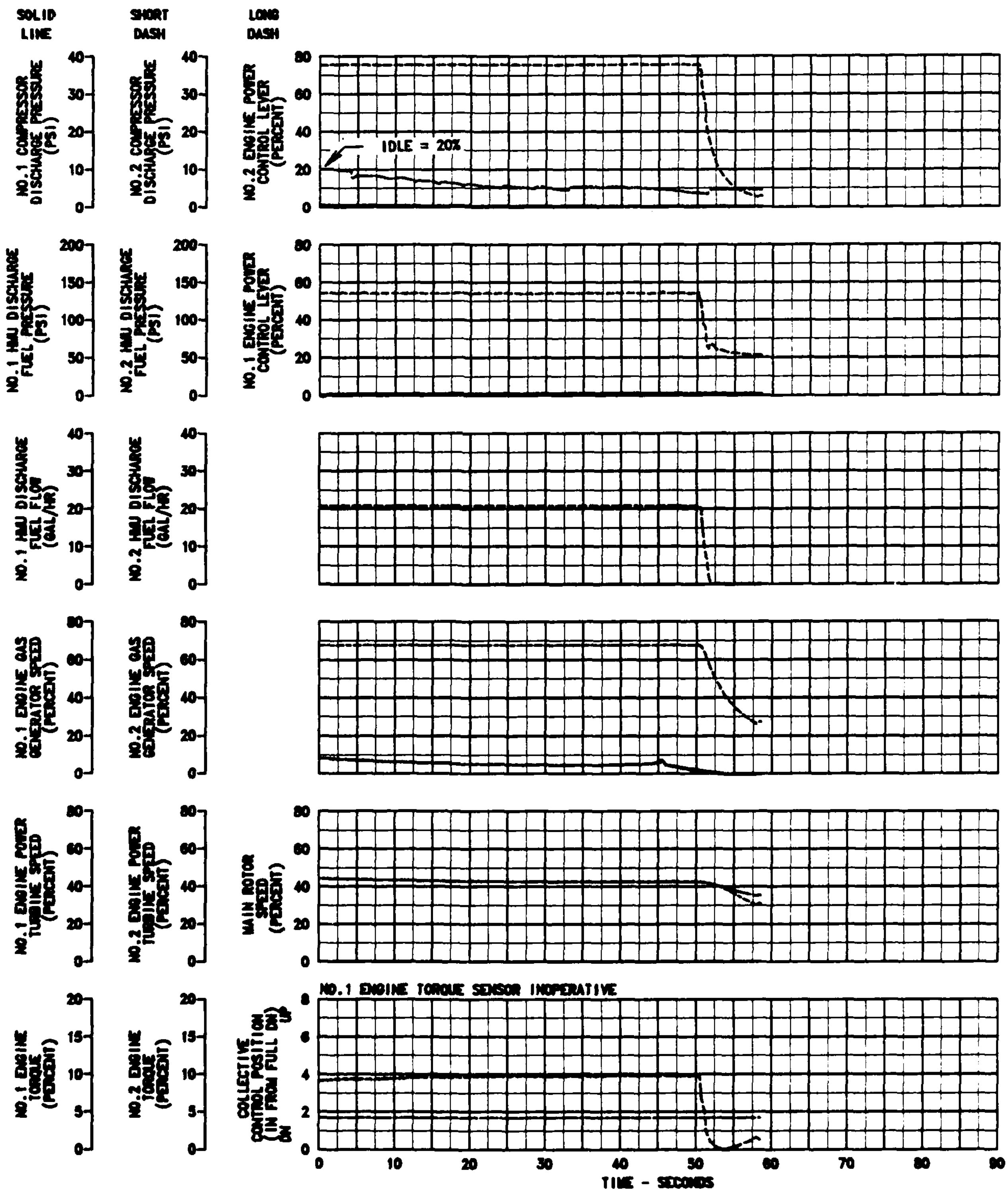


FIGURE E-20
SUB-IDLE FUEL FLOW MODULATION
UH-60A USA S/N 88-26015

PRESSURE ALTITUDE (FEET)	OAT (DEG C)	INDICATED AIRSPEED (KNOTS)
2200	23.5	0

NOTES: 1. HAMILTON STANDARD HMU S/N UDAJ5284 INSTALLED ON ENGINE NO.1
2. INTERIM WOODWARD HMU S/N WYG54238 INSTALLED ON ENGINE NO.2



DISTRIBUTION

HQDA (DALO-AV)	1
HQDA (DALO-FDQ)	1
HQDA (DAMO-HRS)	1
HQDA (SARD-PPM-T)	1
HQDA (SARD-RA)	1
HQDA (SARD-WSA)	1
Commander, US Army Material Command (AMCDE-SA, AMCDE-P, AMCQA-SA, AMCQA-ST)	4
Commander, US Training and Doctrine Command (ATCD-T, ATCD-B)	2
Commander, US Army Aviation Systems Command (AMSAV-8, AMSAV-Q, AMSAV-MC, AMSAV-ME, AMSAV-L, AMSAV-N, AMSAV-GTD)	8
Commander, US Army Test and Evaluation Command (AMSTE-TE-V, AMSTE-TE-O)	2
Commander, US Army Logistics Evaluation Agency (DALO-LEI)	1
Commander, US Army Materiel Systems Analysis Agency (AMXSY-RV, AMXSY-MP)	8
Commander, US Army Operational Test and Evaluation Agency (CSTE-AVSD-E)	2
Commander, US Army Armor School (ATSB-CD-TE)	1
Commander, US Army Aviation Center (ATZQ-D-T, ATZQ-CDC-C, ATZQ-TSM-A, ATZQ-TSM-S, ATZQ-TSM-LH)	5
Commander, US Army Combined Arms Center (ATZL-TIE)	1

Commander, US Army Safety Center (PESC-SPA, PESC-SE)	2
Commander, US Army Cost and Economic Analysis Center (CACC-AM)	1
US Army Aviation Research and Technology Activity (AVSCOM) NASA/Ames Research Center (SAVRT-R, SAVRT-M (Library)	3
US Army Aviation Research and Technology Activity (AVSCOM) Aviation Applied Technology Directorate (SAVRT-TY-DRD, SAVRT-TY-TSC (Tech Library)	2
US Army Aviation Research and Technology Activity (AVSCOM) Aeroflightdynamics Directorate (SAVRT-AF-D)	1
US Army Aviation Research and Technology Activity (AVSCOM Propulsion Directorate (SAVRT-PN-D)	1
Defense Technical Information Center (FDAC)	2
US Military Academy, Department of Mechanics (Aero Group Director)	1
ASD/AFXT, ASD/ENF	2
US Army Aviation Development Test Activity (STEBG-CT)	2
Assistant Technical Director for Projects, Code: CT-24 (Mr. Joseph Dunn)	2
6520 Test Group (ENML)	1
Commander, Naval Air Systems Command (AIR 5115B, AIR 5301)	3
Defense Intelligence Agency (DIA-DT-2D)	1
School of Aerospace Engineering (Dr. Daniel P. Schrage)	1
Headquarters United States Army Aviation Center and Fort Rucker (ATZQ-ESO-L)	1

US Army Aviation Systems Command (AMSAV-EP) 1

US Army Aviation Systems Command (AMCPM-BH) 2